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# Estimation of the effects of aircraft noise on residential satisfaction

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ABSTRACT

This study assesses the effects of aircraft noise on residential satisfaction, an important indicator of subjective well-being. A structural equation model is specified that estimates the relationships between objective variables, noise annoyance variables and residential satisfaction. Secondary data-analysis is used to estimate the model. The survey was conducted in 1996/1997 among the population living within a 25-km radius of Amsterdam Schiphol, the largest airport in the Netherlands. The effect of aircraft noise annoyance is found to be relatively small. In addition, the objective level of aircraft noise exposure is found to be a better predictor of residential satisfaction than its subjective counterpart. The most important determinants of residential satisfaction are found to be road traffic noise annoyance, age and neighbor noise annoyance.



## 1. Introduction

To assess the effects of aircraft noise exposure in residential areas its relationships with objective (e.g. high blood pressure, anxiety, depression) and subjective (e.g. annoyance, qualify of life) outcome indicators need to be studied. We assess the relative importance of aircraft noise exposure vis-à-vis other environmental stressors. This is done by studying the effects of aircraft noise exposure in a holistic framework that includes multiple determinant and criterion variables. Specifically, we investigate the relationships between aircraft noise exposure and two subjective criterion variables: aircraft noise annoyance and residential satisfaction. In addition, various personal and household variables as well as other noise-related subjective determinants of residential satisfaction, i.e. road, railway, construction and neighbor noise annoyance, are included in the analysis. The idea is that by studying the effect of aircraft noise exposure within such an integrated model, vis-à-vis other determinants and using multiple criterion variables like annoyance and residential satisfaction, its relative effect on subjective well-being can be properly assessed.

Residential satisfaction as the final criterion variable is selected because it can be identified as an important indicator of subjective well-being. It has been shown to be associated with other important constructs like life satisfaction (Fried, 1984), psychological well-being (Phillips et al., 2005) and perceived health (Kroesen et al., 2008b).

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## 2. Model development

### 2.1. Theoretical background

Work investigating the determinants of residential satisfaction initially focused on objective attributes of residents. In this respect variables like tenure status (home-owner/rental), income, education, race, presence of children and the duration of residence, have been found to significantly correlate with measures of residential satisfaction (Amerigo and Aragones, 1990).

The sometimes weak relationships between objective characteristics and residential satisfaction, however, led to the belief that objective variables alone did not suffice as determinants of residential satisfaction. Galster and Hesser (1981) formulated and tested the idea that the effects of objective attributes, which they grouped into compositional, those relating to the individual household, and contextual variables, those relating to the physical conditions of the surrounding neighborhood, are partially or wholly mediated via subjective assessments of more limited aspects of the physical or social environment. Indeed, they found both indirect and direct effects of the included objective attributes. Parkes et al. (2002) found, however, the influence of objective socio-demographic variables to be of little influence compared to subjective evaluations related to aspects like housing, crime, safety, neighbors, noise and appearance. This observation is also supported by the work of Lee and Guest (1983).

Overall, it can be concluded that the determinants of residential satisfaction include both objective attributes and subjective evaluations, both personal and environmental characteristics, and social and physical elements.

### 2.2. Model specification

The study concerns a secondary analysis of data gathered in 1996/1997. The variables present in this dataset are integrated into a single model based on the two theoretical notions: first, objective and subjective variables are both assumed to influence residential satisfaction and second, objective variables can influence residential satisfaction either directly or indirectly via the subjective ones (Fig. 1). Of the measurements in the survey, 18 personal background variables and six subjective variables are identified as relevant and included in the model to explain residential satisfaction. The subjective variables relate to annoyance from the following noise sources in the residential environment: aircraft, slow road traffic (<50 km/h), fast road traffic (>50 km/h), railway, construction/demolition/renovation activities[1] and neighbors.

Moving from the theoretical concept, we continue in an explorative fashion and do not hypothesize about individual effects *a priori*. Instead all possible relationships along the hypothesized causal direction (i.e. objective characteristics → subjective assessments → residential satisfaction) are estimated. Via deletion of the insignificant paths the most parsimonious model will be derived.

This strategy also ensures that a direct relationship between aircraft noise exposure and residential satisfaction is estimated. This relationship is included to account for possible pathways, other than through aircraft noise annoyance, through which aircraft noise exposure might influence residential satisfaction. Since there is evidence that the range of subjective reactions to noise is broader than annoyance (covering aspects like fear, anxiety, anger, disappointment, etc.) the existence of these pathways is plausible (Job et al., 2001). Through inclusion of a direct effect between aircraft noise and residential satisfaction these pathways are accounted for.

## 3. Method

### 3.1. Data

To estimate the structural equation model a dataset from a community survey conducted in 1996/1997 is used. Within this study a stratified random sample of 31,000 addresses was drawn from the population living within the 25-km radius around the airport (Fig. 2). Stratification was necessary to adequately represent the full range of aircraft noise exposure. The strata were based on the combination of the distance from the airport and the level of aircraft noise exposure. In practice, this approach resulted in an over-sampling of people living close to the airport. To arrive at a sample which is representative for the population within the 25-km radius of Amsterdam Schiphol the observations were therefore re-weighted to take the stratified study design into account.

Approximately 1.5 million people aged 18 or over live in the survey area. The data were gathered via a postal questionnaire with a response rate of 39%.[2] Cases with more than 10% missing values are deleted. Of the remaining missing values of the variables used in the analysis, 1.2% of all entries, are imputed via the expectation–maximization algorithm of SPSS 14.0. The resulting dataset consisted of 10,746 complete cases.

[1] For the sake of brevity we will refer to this source as 'construction noise'.

[2] For more detailed descriptions of this study see: TNO-RIVM (1998), Miedema et al. (2000) and Franssen et al. (2004).

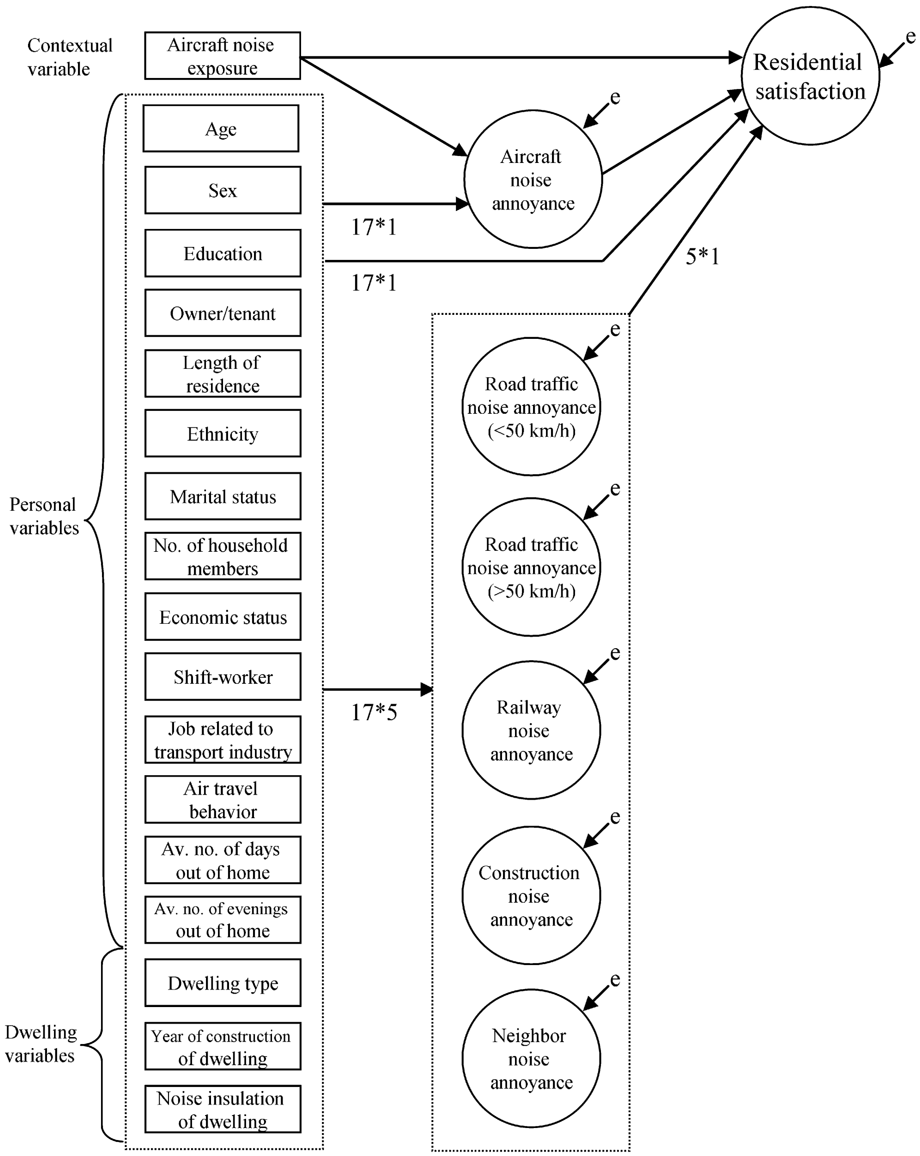


**Fig. 1.** Theoretical model of the effects of aircraft noise exposure on residential satisfaction.

### *3.2. Measures*

#### *3.2.1. Individual, household, dwelling and contextual characteristics*

Table 1 shows the 18 objective variables and their re-weighted sample distributions. The variables cover a broad range of socio-demographic characteristics related to a subject's economic status and dependency on the aviation industry, household and dwelling characteristics and the level of aircraft noise exposure. Assuming that these variables are measured without errors they are directly included in the structural equation model as observed variables.

For age non-linear relationships with dependent variables in the model were expected (Miedema and Vos, 1999). Based on three categories (1: 'young' = 18–30 years, 2: 'middle-aged' = 31–55 years and 3: 'old' $\geqslant$ 56 years), age was thus recoded into two indicator variables using the effect coding principle.

All variables, except the level of aircraft noise exposure (Table 1), are self-reported. Using a method legally prescribed in the Netherlands (Rijksluchtvaardienst, 1996), the level of aircraft noise exposure around Schiphol airport was calculated by the Dutch National Aerospace Laboratory for all subjects in the dataset. These calculations are based on the actual flight data (time, takeoff or landing, type of aircraft, flight path recorded by the flight tracking system) for each flight in the year

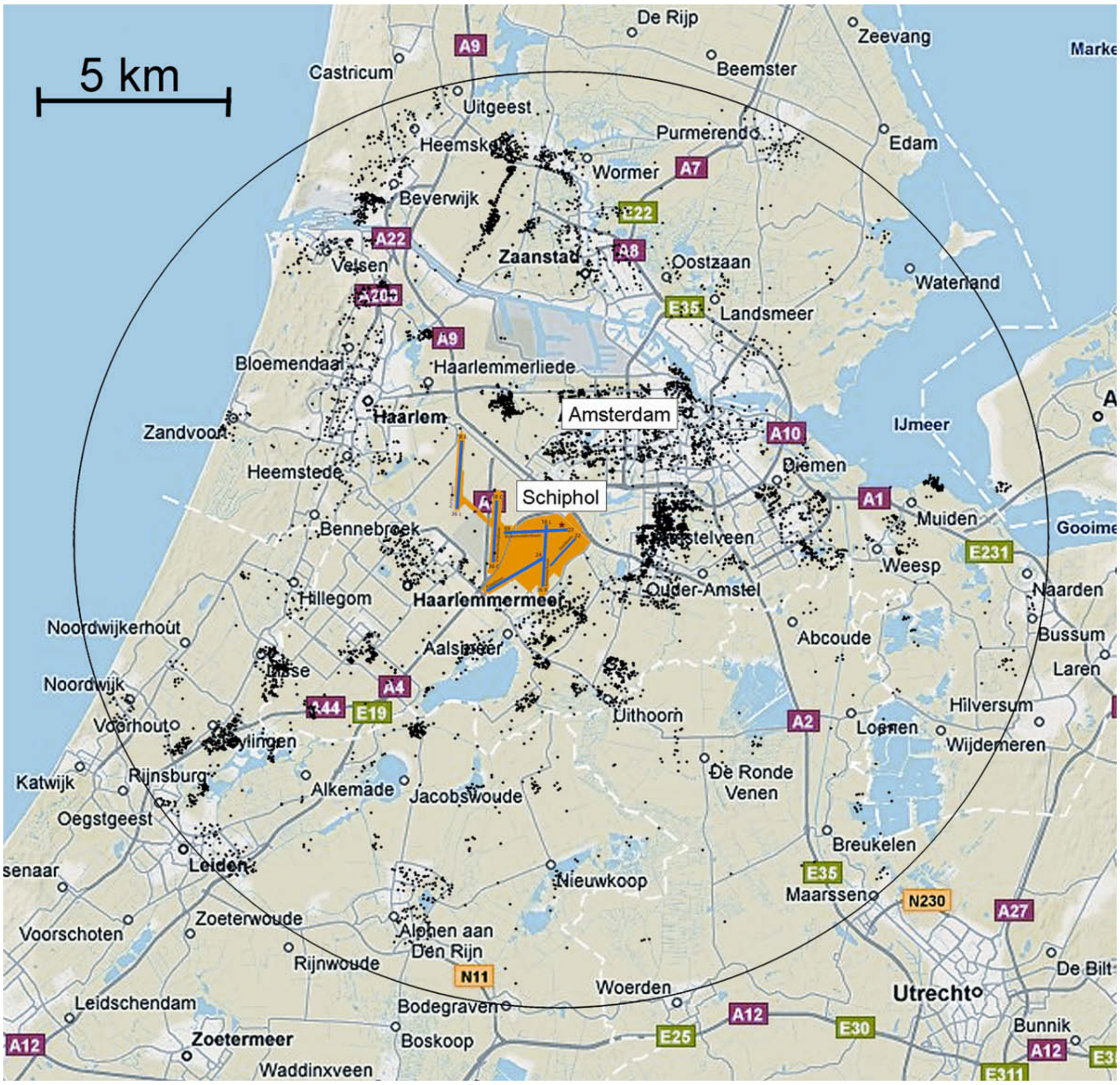


**Fig. 2.** Survey area.

preceding the survey. Here the $L_{den}$ (i.e. level day–evening–night in dB(A)) is selected as a measure of the level of aircraft noise exposure.[3]

### 3.2.2. Measurement model

The noise-annoyance constructs are subjective in nature. To correct these constructs for structural and random measurement errors, they are measured indirectly via multiple items. This results in less biased estimates between the structural variables in the model.

For the measurement model six latent variables are defined, one for each noise annoyance construct in Fig. 1. Each variable is operationalized using two items related to the following questions: (Item 1) 'How annoying or not annoying is the noise of the following sources according to you at home?' (response ranging from 0 = 'not at all annoying' to 10 = 'very annoying') and (Item 2) 'to what extent is your sleep disturbed by the following noise sources?' (responses ranging from 0 = 'not at all disturbed' to 10 = 'very much disturbed'). The model is specified assuming each set of two measures indicates its corresponding latent construct and allowing all latent constructs to correlate.[4]

[3] $L_{den}$ is an equivalent sound level of 24 h expressed in decibels (dB) on the '*A*' weighted scale dB(A). Sound levels during the evening (7–11 pm) and during the night (11–7 am) are increased by a penalty of 5 and 10 dB(A) respectively. This metric is also selected by the European Council to monitor and assess noise problems in its member states.

[4] It is estimated using the structural equation modeling software package Lisrel 8.8.

**Table 1**
Re-weighted sample distributions of objective variables in dataset.

| Observed variable | Range/description | Freq. | % | Mean | SD |
|---|---|---|---|---|---|
| 1. Age (years) | <20 | 160 | 1.5 | 46.2 | 15.7 |
| | 21–40 | 4279 | 39.8 | | |
| | 41–60 | 3974 | 37.0 | | |
| | 61–80 | 2039 | 19.0 | | |
| | >80 | 168 | 1.6 | | |
| | Missing | 125 | 1.2 | | |
| 2. Sex | Male | 5668 | 52.7 | | |
| | Female | 4992 | 46.5 | | |
| | Missing | 86 | 0.8 | | |
| 3. Education | No education | 47 | 0.4 | | |
| | Primary school | 468 | 4.4 | | |
| | Secondary school | 4489 | 41.8 | | |
| | Higher education | 3929 | 36.6 | | |
| | University | 1408 | 13.1 | | |
| | Missing | 404 | 3.8 | | |
| 4. Dwelling ownership | Rental | 4739 | 44.1 | | |
| | Owner-occupied | 5887 | 54.8 | | |
| | Missing | 120 | 1.1 | | |
| 5. Length of residence (years) | 0–10 | 5980 | 55.6 | 12.4 | 11.3 |
| | 11–20 | 2323 | 21.6 | | |
| | 21–30 | 1368 | 12.7 | | |
| | 31–40 | 879 | 8.2 | | |
| | Missing | 196 | 1.8 | | |
| 6. Ethnicity | Dutch | 9871 | 91.9 | | |
| | Other than Dutch | 585 | 5.4 | | |
| | Missing | 290 | 2.7 | | |
| 7. Marital status | Single | 3453 | 32.1 | | |
| | Married/living together | 7174 | 66.8 | | |
| | Missing | 119 | 1.1 | | |
| 8. Household size (number of household members) | 1 | 2667 | 24.8 | 2.4 | 1.2 |
| | 2 | 4100 | 38.2 | | |
| | 3 | 1461 | 13.6 | | |
| | 4 | 1673 | 15.6 | | |
| | ⩾5 | 693 | 6.5 | | |
| | Missing | 150 | 1.4 | | |
| 9. Economic status | Part-time/full-time employed | 7891 | 73.4 | | |
| | Unemployed | 2684 | 25.0 | | |
| | Missing | 171 | 1.6 | | |
| 10. Shift-worker (working in evening/night time so one is forced to sleep during the day) | No | 9633 | 89.6 | | |
| | Yes | 952 | 8.9 | | |
| | Missing | 160 | 1.5 | | |
| 11. Job related to air transport industry | No | 9975 | 92.8 | | |
| | Yes | 637 | 5.9 | | |
| | Missing | 134 | 1.2 | | |
| 12. Air travel behavior | Did not fly in last 2 years | 4550 | 42.3 | | |
| | Did fly in last 2 years | 6137 | 57.1 | | |
| | Missing | 58 | 0.5 | | |
| 13. Average number of days out of home per week | 0 | 2616 | 24.3 | 2.9 | 2.2 |
| | 1 | 958 | 8.9 | | |
| | 2 | 928 | 8.6 | | |
| | 3 | 933 | 8.7 | | |
| | 4 | 1020 | 9.5 | | |
| | 5 | 3441 | 32.0 | | |
| | 6 | 504 | 4.7 | | |
| | 7 | 120 | 1.1 | | |
| | Missing | 226 | 2.1 | | |
| 14. Average number of evenings out of home per week | 0 | 3211 | 29.9 | 1.5 | 1.4 |

**Table 1** (*continued*)

| Observed variable | Range/description | Freq. | % | Mean | SD |
|---|---|---|---|---|---|
| | 1 | 2565 | 23.9 | | |
| | 2 | 2468 | 23.0 | | |
| | 3 | 1328 | 12.4 | | |
| | 4 | 640 | 6.0 | | |
| | 5 | 229 | 2.1 | | |
| | 6 | 62 | 0.6 | | |
| | 7 | 27 | 0.3 | | |
| | Missing | 215 | 2.0 | | |
| 15. Dwelling type (detachedness) | Flat or apartment | 3832 | 35.7 | | |
| | Row house | 5030 | 46.8 | | |
| | Semi-detached | 816 | 7.6 | | |
| | Detached | 781 | 7.3 | | |
| | Missing | 288 | 2.7 | | |
| 16. Year of construction of dwelling | Before 1900 | 699 | 6.5 | | |
| | 1900–1944 | 2283 | 21.2 | | |
| | 1945–1979 | 4572 | 42.5 | | |
| | 1980 and later | 2916 | 27.1 | | |
| | Missing | 276 | 2.6 | | |
| 17. Noise insulation of dwelling | No | 6209 | 57.8 | | |
| | Yes | 3540 | 32.9 | | |
| | Missing | 997 | 9.3 | | |
| 18. Aircraft noise exposure (dB(*A*) $L_{den}$) | <50 | 805 | 7.5 | 53.7 | 2.6 |
| | 50.1–55.0 | 6793 | 63.2 | | |
| | 55.1–60.0 | 3017 | 28.1 | | |
| | >60.1 | 131 | 1.2 | | |

The results show that the measurement model provides a reasonable fit to the data.[5] The modification indices indicate that model can be improved through specification of additional correlations between the second items of the latent variables, namely those relating to the 'sleep disturbance' questions. Theoretical justification for these correlations lies in evidence that people vary in their sensitivity to be awakened by noise (Anderson and Miller, 2007), causing the additional structural covariation between these items. After specification of these 15 correlations and re-estimation, the model fit improved significantly with all indices showing an acceptable fit.[6]

Based on the model fit results and evidence of construct validity, present in terms of convergent and discriminant validity (not presented), one may conclude that the measurement model is well specified.

### *3.2.3. Residential satisfaction*

Finally, we will focus on the operationalization of the main dependent variable, residential satisfaction. This variable also represents a subjective evaluation but it was not included in the measurement model because only one item suitable to proxy this concept was available (making it impossible to define a multiple item latent variable). This item related to the question: 'how satisfied are you with living in this residential environment?' The re-weighted sample distribution in response to this question was: 8.9% extremely satisfied, 29.2% very satisfied, 50.4% satisfied, 8.4% not so satisfied, 2.0% dissatisfied and with the remainder missing.

Since only one indicator of residential satisfaction is available it is not possible to provide an estimate for its reliability. Instead of assuming its reliability to be 100%, however, the item is assumed to be measured with the same reliability as the average reliability (Cronbach's alpha) of the six noise-annoyance constructs, an assumption more likely to reflect its true reli-

[5] Since the chi-square statistic is sensitive to sample sizes over 500 and thus expected to be significant indicating a lack of fit, we included the indices independent of sample size to evaluate the fit of the model. These are the root mean square error of approximation (RMSEA) (Browne and Cudeck, 1993), which measures the discrepancy between the model implied and observed covariance matrix per degree of freedom, the standardized root mean residual (SRMR) (Bentler, 1995), which measures the mean of the squared residuals (the differences between the sample and model-implied covariance matrices) divided by the standard deviations of the respective manifest variables, and the comparative fit index (CFI) (Bentler, 1990), which provides a comparison between the specified model and a baseline model with zero constraints. A well-fitting model is defined as having values below 0.06 and 0.08 for RSMEA and SRMR respectively and a CFI value greater than 0.95 (Hu and Bentler, 1999). The parameters obtained are S-B scaled $\chi^2_{d.f.=39} = 2848.53$, RMSEA = 0.082, CFI = 0.944, SRMR = 0.0290.

[6] S-B scaled $\chi^2_{d.f.=24} = 142.96$, RMSEA = 0.021, CFI = 0.998, SRMR = 0.0102.

**Table 2**
Standardized total effects on dependent variables (all sign. at $p < 0.001$) and percentages of explained variance.

| | Direct effects on noise-annoyance constructs | | | | | | Effects on residential satisfaction | | | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| | Aircraft noise annoyance | Road traffic noise annoyance (<50 km/h) | Road traffic noise annoyance (>50 km/h) | Railway noise annoyance | Construction noise annoyance | Neighbor noise annoyance | Direct | Indirect | Total | |
| Road traffic noise annoyance (<50 km/h) | – | – | – | – | – | – | −0.254 | – | −0.254 | 1 |
| Age (young) → age1 | −0.119 | 0.090 | 0 | 0.036 | 0.190 | 0.260 | −0.072 | −0.063 | −0.135 | 2 |
| Age (middle-aged) → age2 | 0.204 | 0.182 | 0.077 | 0.070 | 0.120 | 0.210 | 0.051 | −0.104 | −0.053 | |
| Age (old) → −age1 + −age2 | −0.085 | −0.272 | −0.077 | −0.106 | −0.310 | −0.470 | 0.021 | 0.167 | 0.188 | |
| Neighbor noise annoyance | – | – | – | – | – | – | −0.180 | – | −0.180 | 3 |
| Aircraft noise exposure | 0.307 | 0 | 0 | 0.035 | 0 | 0 | −0.123 | −0.021 | −0.144 | 4 |
| Dwelling ownership (owner-occupied) | 0.066 | 0 | 0 | 0 | 0 | −0.108 | 0.127 | 0.016 | 0.143 | 5 |
| Year of construction of dwelling | −0.057 | −0.142 | 0 | 0 | −0.120 | 0 | −0.138 | 0.039 | −0.099 | 6 |
| Dwelling type (detachedness) | 0.041 | 0 | 0.093 | 0 | −0.175 | −0.236 | 0.061 | 0.035 | 0.096 | 7 |
| Length of residence | −0.043 | 0 | 0 | 0 | 0 | 0.107 | −0.072 | −0.017 | −0.089 | 8 |
| Air travel behavior (did fly in last 2 years) | −0.068 | 0 | 0 | 0 | 0 | 0 | 0.072 | 0.004 | 0.076 | 9 |
| Aircraft noise annoyance | – | – | – | – | – | – | −0.064 | – | −0.064 | 10 |
| Average number of evenings out of home per week | 0 | 0 | 0 | 0 | 0.070 | 0 | 0.054 | 0 | 0.054 | 11 |
| Road traffic noise annoyance (>50 km/h) | – | – | – | – | – | – | −0.048 | – | −0.048 | 12 |
| Shift-worker (yes) | 0.030 | 0 | 0 | 0 | 0.037 | 0.044 | −0.034 | −0.010 | −0.044 | 13 |
| Household size | 0 | −0.103 | 0 | 0 | −0.079 | −0.100 | 0 | 0.044 | 0.044 | 14 |
| Marital status (married/living together) | 0.059 | 0.102 | 0 | 0 | 0 | 0.076 | 0 | −0.043 | −0.043 | 15 |
| Railway noise annoyance | – | – | – | – | – | – | −0.040 | – | −0.040 | 16 |
| Education | 0.118 | 0.037 | 0 | 0 | 0.140 | 0.071 | 0 | −0.030 | −0.030 | 17 |
| Economic status (unemployed) | 0 | 0.059 | 0 | 0 | 0.093 | 0.069 | 0 | −0.027 | −0.027 | 18 |
| Noise insulation of dwelling (yes) | −0.065 | 0 | 0.041 | 0 | 0 | −0.054 | 0 | 0.012 | 0.012 | 19 |
| Sex (female) | 0 | 0 | 0 | −0.034 | 0.064 | 0.043 | 0 | −0.006 | −0.006 | 20 |
| Job related to air transport industry (yes) | −0.036 | 0 | 0 | −0.047 | 0 | 0 | 0 | 0.004 | 0.004 | 21 |
| Average number of days out of home per week | 0 | 0 | 0 | 0 | −0.109 | 0 | 0 | 0 | 0 | 22 |
| Ethnicity (other than Dutch) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 |
| Construction noise annoyance | – | – | – | – | – | – | 0 | – | 0 | 22 |
| Percentage of variance explained (%) | 17.2 | 6.1 | 1.6 | 1.1 | 17.6 | 21.6 | | | 24.4 | |

0 = Non-significant (fixed at zero).

ability. The reliability is taken into account by including the item in the model as an observed variable of a corresponding latent variable and fixing its error variance at (1–0.767) multiplied by the variance of the observed item (Kelloway, 1998).

## 4. Results and discussion

### 4.1. Estimation of the full structural equation model

The objective characteristics, as directly observed variables, the noise-annoyance constructs, as indirectly observed latent variables, and residential satisfaction, as a single-indicator latent variable, are included in the structural equation model as seen in Fig. 1. All objective attributes, the exogenous variables, are allowed to correlate. As a result, the effects of each on endogenous variables later in the causal chain are controlled for the effects of all other exogenous variables. Similarly, at the level of the noise-annoyance constructs, which are endogenous, and thus have error terms, the error terms of these variables are allowed to correlate. Again to ensure that the effect of each noise annoyance variable on residential satisfaction is controlled for the effects of all other noise annoyance variables.

The first step is to estimate a fully saturated structural model in which all paths between structural variables are estimated; an estimation of 139 structural parameters. To arrive at a more parsimonious model, all insignificant estimates are deleted. Considering the large sample and the increased chance of finding a significant relationship due to the large number of parameters, the conventional alpha level of 0.05 is lowered to 0.001. This criterion leads to the deletion of 73 insignificant paths.[7]

The standardized effects between the predictors, the six noise-annoyance constructs and residential satisfaction are presented in Table 2 in descending order based on their effect on residential satisfaction. For residential satisfaction, the effects are decomposed into direct and indirect effects.

### 4.2. Effects of aircraft noise on residential satisfaction

A surprising result is that the total effect of aircraft noise exposure ranks higher than the effect of aircraft noise annoyance. In addition to an expected indirect effect via aircraft noise annoyance a large direct effect remains. Hence, with respect to aircraft noise the objective physical condition is a stronger predictor of residential satisfaction than its subjective counterpart. As has been suggested before, a plausible explanation is that aircraft noise annoyance does not capture all negative feelings in response to aircraft noise (Job et al., 2001). The remaining strong direct effect provides additional evidence for this assertion.

In relation to the other noise-related constructs we find that the effect of aircraft noise annoyance, is smaller than the effects of slow road traffic noise annoyance (<50 km/h), and neighbor noise annoyance, but larger than the effects of fast road traffic noise annoyance (>50 km/h), railway noise annoyance, and construction noise annoyance.

The results indicate that, in comparison to other environment effects, aircraft noise is not a strong predictor of residential satisfaction. Since the analysis is based on a representative sample of residents living within the 25-km radius of a large international airport, this finding may be seen as remarkable. The relatively weak link between aircraft noise and residential satisfaction has also been confirmed in a previous study among residents around Schiphol airport (Marsman and Leidelmeijer, 2001). Stallen and Van Gunsteren (2002) explain this finding by speculating that annoyance caused by aircraft noise is part of a different, more political domain of frustrations than residents' feelings about their residential quality.

### 4.3. Effects of personal background variables

After road traffic noise annoyance, age is the main determinant of residential satisfaction. In line with previous work the effect shows that as one grows older one is most positive about the residential environment, but the direct effect of age on residential satisfaction is curvilinear, whereby the middle-aged class is most satisfied with their residential environment. Age also has six indirect effects with residential satisfaction via the noise-annoyance constructs. The effects of age on aircraft, road traffic and railway noise annoyance are also curvilinear, with those in the middle class age reporting most annoyance, a result that has been previously established for aircraft noise annoyance (Miedema and Vos, 1999). The causal mechanism involved might be that, because of a relatively high level of daily mental workload, the adaptive resources of middle-aged people are pushed to the limit by the presence of noise.

The effect of dwelling ownership indicates that home-owners are more satisfied than tenants. Evidence for the existence and significance of this effect has been provided in the past by Parkes et al. (2002), Lu (1999) and Galster and Hesser (1981), and has been explained by incentives for home-owners to maintain their properties at a higher standard and to join organizations that protect their collective interests (Rohe and Stewart, 1996). The indirect effects of dwelling ownership run through aircraft noise annoyance and neighbor noise annoyance. A theoretical justification for the positive effect on aircraft noise annoyance might be that home-owners are concerned about property devaluation due to the aircraft noise, a factor shown to affect the negative appraisal of aircraft noise (Kroesen et al., 2008a). However, the validity of this explanation is

[7] The re-estimated model shows an acceptable model fit (S-B scaled $\chi^2_{d.f.=217} = 1090.52$, RMSEA = 0.019, CFI = 0.993, SRMR = 0.0134).

questionable since this mechanism would also apply to the other transportation noise sources for which no effects are found on the respective noise-annoyance constructs.

The effect of year of construction of the dwelling shows that people in older properties generally have a higher degree of residential satisfaction. This is consistent with a study of McHugh et al. (1990) who reason that older neighborhoods are more established in a community sense and are in better locations relative to jobs and services. In contrast, newer neighborhoods contain more fluid populations and weaker community ties. The indirect effects of year of construction though aircraft, road traffic moving at over 50 km/h, and construction noise annoyances, result in a positive contribution to residential satisfaction. A possible explanation is that newer houses are generally better insulated.

The dwelling type has a positive indirect and direct effect on residential satisfaction. The positive sign of the total effect is consistent with previous research (Marans and Rodgers, 1975). A plausible explanation for the direct effect is that, moving along the dimension of detachedness, the houses are generally bigger resulting in higher levels of housing satisfaction, which, in turn, leads to greater residential satisfaction (Parkes et al., 2002). The indirect effects between dwelling type and residential satisfaction run through aircraft, road traffic (>50 km/h), construction and neighbor noise annoyance. For neighbor noise annoyance an obvious explanation is that higher detachedness leads to lower proximity to neighbors which decreases the perceived noise caused by them.

Length of residence has a negative effect on residential satisfaction. This is inconsistent with some studies that provide evidence of a positive effect (e.g. Marans and Rodgers, 1975), although others offer a significant negative effect including Onibokun (1976) and Lu (1999). Additionally, a part of this negative effect is mediated through neighbor noise annoyance. Living longer in one place increases the annoyance from neighbor noise.

Air travel behavior has a direct effect on residential satisfaction and a very small indirect effect. Individuals who have flown in the previous two years are more satisfied with their residential environment. The indirect effect via aircraft noise annoyance can be explained by the fact that use of the airport leads people to be less annoyed by noise (Miedema and Vos, 1999).

The remaining relationships have a relatively small effect and are less relevant. The effects will therefore not be discussed. Overall, it can be concluded that the signs and sizes of most of the remaining effects are intuitively correct and in line with previous research findings. There is one remaining specific finding which is remarkable. This finding relates to the effect of noise insulation, which is relatively small and only affects residential satisfaction via aircraft, road traffic moving over 50 km/h and neighbor noise annoyance. This finding is potentially interesting because a subset of individuals in the sample even received government funded noise insulation measures especially designed to mitigate the effects of aircraft noise.

### *4.4. Percentages of explained variance*

The percentages of explained variance indicate how well the endogenous variables in the model are predicted. These figures are presented in the bottom row of Table 2. 24.4% of the variance in residential satisfaction is explained, which is reasonably high considering the range of other variables, not included in the study; e.g. safety, air quality, housing attributes, neighborhood appearance/services, social network, and accessibility.

Related to the noise annoyance variables, the objective variables can explain substantial portions of variance in the variables aircraft noise annoyance, construction noise annoyance and neighbor noise annoyance. The objective variables are unable to explain substantial portions of the variance in road traffic noise annoyance and railway noise annoyance.

Nevertheless a large amount of variance in aircraft noise annoyance remains unexplained, which can probably be attributed to the existence of so-called non-acoustical factors not included. These have, next to the noise exposure level, been shown to affect aircraft noise annoyance. Examples include the attitude towards the noise source authorities and the level of perceived control (Kroesen et al., 2008a). These social-psychological variables are also likely to play a role in the explanation of the other noise-annoyance constructs in which also large portions of variance remain unexplained.

## 5. Conclusion

This study looked at the effects of aircraft noise on residential satisfaction around Amsterdam Schiphol within a holistic framework that included exogenous objective variables relating to the individuals, the dwellings and the context, as well as the mediating role of subjective noise annoyance variables. The analysis shows that the most important determinants of residential satisfaction are road traffic noise annoyance age and neighbor noise annoyance. Unexpectedly results include a strong direct effect between aircraft noise exposure and residential satisfaction that remains after accounting for the indirect relationship via aircraft noise annoyance. This is consistent with the idea that aircraft noise annoyance is unlikely to fully capture all negative reactions in response to aircraft noise. Additionally, the effect of sound insulation is very small, indicating that it only marginally increases residential satisfaction.

Following Marans (2003) the study provides a holistic analysis into the relationships between objective attributes and subjective perceptions and evaluations of the residential environment. In applying this perspective, insights are gained into the relative importance of different variables in relation to residential satisfaction, an important indicator of subjective well-being. These insights can be valuable in the design and planning of measures that affect residential quality.

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