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Stated preference analysis of a new very light jet based on-demand air service

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Abstract

This paper develops behavior models to analyze traveler propensity towards a new "very light jet"-based on-demand air service (ODAS), also labeled air taxi service, with the broader objective of providing guidance for the enabling stakeholders including business operators, policy-makers and aircraft manufacturers. The models predict the probability of individuals switching from their usual preferred mode of intercity transportation (up to 960 km) to the ODAS under a range of scenarios in terms of travel distance and cost. Travel distance, service fare, and level of accessibility are identified as key determinants of the viability of the ODAS. Analysis of the models provides insights for operational/business strategies in the private sector (both for aircraft manufacturers and the ODAS operators), for policy-making in the public sector, and for understanding the potential barriers to the evolution of ODAS as a viable intercity travel option.

Keywords: on-demand air service; very light jets; econometric analysis.

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1. Introduction

Transformation of the U.S. air transportation system is underway as evidenced by shifts in both the private industry and public sector. The industry is transforming due to the combined pressures of fare competition, fuel price increases, and limitations on flexibility in reducing overall operational costs, as well as new opportunities enabled by technological advances. Mainline carriers are seeking to remold service and cost structure to compete for fare-conscious travelers being increasingly attracted by low-cost carriers. A key consequence of this transformation is that the number of operations in the system is increasing. Also, general demand is surpassing pre-9/11 levels. Consequently, operational congestion is a regular feature of key airports around the country. This precludes slack to allow for significant random events such as debilitating weather-related incidents, operational malfunctions, and system component failures. Given the strong interdependencies manifested in the air transportation network (for example, due to hub-and-spoke type operational structures), cascading effects across the system geographically can cripple a substantial part of the air transportation system. This has implications for the economy and the robustness of service levels. Due to this multiplicity of issues in the evolution of the air transportation system, the government is seeking to transform air transportation planning to face the system-wide challenges brought by more operations and increasing demand, especially in areas of capacity and reliability. Within the mixture of both private and public sector convulsions, new ideas are emerging that could impact the "transformational" interests of both groups. One such idea is the introduction of a new type of service called "On-demand Air Service" (ODAS), partially derived from research conducted over the past five years in the NASA Small Aircraft Transportation System (SATS) program (Holmes, et al., 2004). In contrast to scheduled commercial air service, ODAS is envisioned to be based "on-demand", point-to-point, and more accessible (that is, will also use local airports). It represents an extremely flexible service that may be attractive to consumers seeking efficient doorstep-to-doorstep travel while also relieving congestion at hub airports which is the primary source of delay in the larger air transportation system.

ODAS, in a limited sense, exists in today's system in the form of private/corporate jets, fractional ownership operations (e.g. NETJETS), and, in some cases, privately owned general aviation aircraft used for personal transportation. There are two important interrelated traits shared amongst these three examples. First, they are usually available "on-demand" - when and where the traveler desires. Second, they are expensive relative to alternate modes and thus currently constitute an extremely small portion of the market for air operations. There is a growing conviction within the aviation community that a more widely available on-demand service could not only be possible, but is also crucial to solving present and increasingly worsening future air transportation congestion problems (FAA, 2004). However, significant uncertainty remains regarding the conditions for actual viability.

The viability of a new, more widely available ODAS hinges on three developments: new aircraft technology, new business models, and operational and management policies that allow optimal use of existing and new infrastructure resources. The first is already quite far along, with a new generation of small affordable jet aircraft (termed "microjets" or "very light jets" (VLJs)) having been designed, marketed, and certified. These aircraft weigh less than 10,000 pounds at take-off, require low maintenance, entail high reliability, provide significant speed advantage (upwards of 40%) over similar-sized turboprop aircraft, and require much shorter runways than larger jets. Consequently, they can use the more than 5000 local/satellite U.S. airports, substantially increasing locational accessibility. There are several VLJs already in production, notably the Eclipse Aviation Eclipse 500 (Harness, 2003). Industry analysts predict that between 5000-10000 VLJs may operate in the U.S. airspace by 2015. New business models have been proposed that seek to exploit both the new aircraft technology and the market needs for more attractive solutions. The price point for these new models is below those of the corporate jet or fractional ownership markets. Indeed, some are characterizing their operation as "air-taxi", and examples exist of regional service which intends to use small un-crowded airports close to where people live and/or work. It is quite plausible that as such service is proven to be both safe and effective, and as further innovation due to market pressure ensues, the ODAS will improve and expand to include a wide range of citizens who can afford the utility that the service brings. The status of the third required ingredient for successful growth of ODAS, proper operational/management policies, remains less clear. The successful fruition of the ODAS potential is dependent on the adequate and convenient interconnection with other modes, proper access within the communities of users, adequate attention to environmental considerations, and the strategic understanding of its role and potential evolution relative to the multimodal national transportation system. Effective policy-making requires that stakeholder groups have an informed understanding of these dependencies. As will be discussed hereafter, deriving insights on some aspects of this third element represents the primary motivation for the current study.

In the short-term, the most promising role for the ODAS is in the context of intercity travel involving the short to medium distance ranges. However, the aforementioned vision for the ODAS, taken to its logical limit under favorable evolution scenarios and symbiotic polices, suggests the possibility of the aircraft becoming a primary personal commuting mode in the long-term, akin to the personal automobile in the early twentieth century. Presumably, an individual could live in a desired location significantly further away than a suburb, and commute to work using the microjet mode. However, the transformational role of auto vis-à-vis personal transportation was aided by three synergistic developments over a few decades: the affordability of auto ownership due to Ford's innovations in the private sector; federal policies that increased the accessibility of mortgage loans and the consequent demographic shifts to the suburbia; and the construction of a national system of express highways. This suggests the need to understand the short-term perspectives of stakeholders (operators, users, policymakers, manufacturers), and their implications for the long-term evolution of ODAS, as well as the longer-term risks, incentives, interdependencies, and policies that lead to microjets being a realistic personal commute mode. The overarching motivation for the proposed research is to establish the foundation for the systematic consideration of the short-term and long-term interdependencies stemming from advances in transportation technologies, consumer preference, planning policies, and business development. The specific focus of the paper is on understanding traveler attitudes towards ODAS as a potential intercity travel mode, thereby providing policy-makers and business operators insights for developing short-term strategies and implications for the long-term planning.

1.1. *ODAS and the multimodal transportation market*

The key mobility metric underpinning interest in ODAS is doorstep-to-doorstep (D-D) travel time, as illustrated in Fig. 1. Autos provide fairly reliable, but lengthy D-D travel time for intercity trips. However, this travel is increasingly exacerbated by urban congestion and/or the consequences of accidents. Further, the traveler is most often the driver, and the resulting stress further affects the trip quality. Scheduled commercial air operations provide often unreliable, and not significantly lower D-D travel time for moderate length intercity trips, especially when flight connections are required. In addition, there is a need to use auto, transit, or taxi service to access the major airports and to reach the final destination, increasing travel time and reducing reliability for the entire trip. ODAS represents a new mobility resource; it is envisioned to operate point-to-point, will be accessible at more locations closer to where people live or work, and with schedule flexibility, unlike the scheduled commercial operations. Further, the ease of locational access of ODAS will reduce the dependency on the vagaries of ground transportation (auto, transit, taxi, etc.) at both the origin and destination.

While the proposition of ODAS is compelling, it is not yet a proven service in the market. Further, its widespread deployment would significantly transform U.S. air space management. Hence, there are numerous questions both on the demand and supply sides that need to be addressed before an effective deployment of an ODAS becomes possible. An immediate question concerns the preference, acceptance, and reactions among future customers towards the new ODAS. This is important because customer acceptance will significantly influence ODAS viability. Hence, an understanding of the customer behavior towards an ODAS, and the characteristics of an ODAS that would increase its attractiveness for the customer, are essential first steps. However, there are three challenges to understanding the ODAS demand characteristics. First, the ODAS necessarily operates as part of a multimodal transportation system; hence, an understanding of its attractiveness requires the juxtaposition of other "competing" modes. Second, the ODAS represents a recent transportation option: technologically, as a business model, and as a transportation alternative. Hence, the lack of familiarity, or a generic understanding of option among the potential customer base, makes it difficult to gauge the attitudinal aspects of decision-making with regard to ODAS. Third, and as a follow-up to the second challenge, is the issue of timescale. Experience with the ODAS will provide more definitive indicators for the potential customers on which attributes influence their decision-making significantly. Cognizant of these limitations, the proposed study seeks to understand the causal factors for the viability of ODAS, as discussed further in the next sub-section. The objectives are to provide directions for operational/business strategies in the private sector (both for aircraft manufacturers and the ODAS operators) and for policy-making in the public sector, and to understand the potential barriers to the evolution of ODAS as a legitimate intercity travel option.

1.2. Study objectives

The primary objective of this study is to build traveler behavior models that predict the probability of individuals switching from the usual preferred mode of intercity transportation to the new ODAS under a range of plausible scenarios in terms of travel distance and cost. Only regional intercity trips of up to 960 kilometers (600 miles) are considered; while larger distances can entail the ODAS as a possible alternative, we focus on a distance range where both auto and commercial air modes are the primary preferred modes. Prior analysis of future air transportation options (DeLaurentis et al., 2004) indicated that the 240-960 kilometers (150-600 mile) distance range was the interval for plausible competitiveness of personal use aviation for transportation. These findings are also consistent with those of Holmes, et al. (2004). It is expected that the behavior models will lead to the understanding of how trip and mode characteristics would influence traveler decision-making relative to the ODAS mode. In addition, this study seeks insights on attitudinal differences among different population segments for a more effective deployment of the new ODAS. These insights will generate implications for future operational policies for the ODAS concept.

The study conducts an econometric analysis of mode choice to understand the likely preferences of individuals in the ODAS context. As the ODAS is not yet available, and the consequent lack of widespread familiarity with it, stated preference (SP) survey of travelers is conducted to develop the models. The survey provides a brief description of the ODAS to the respondents. The behavior models developed in this study also provide inputs to an agent-based model that predicts the plausible trajectories for the evolution of the future national transportation system (Lewe and DeLaurentis, 2004). Further, analysis of the customer preferences is also expected to provide indicators to the aircraft manufacturers and ODAS operators for developing integrated business models that marry operator service strategies with aircraft design options.

The remainder of this paper is organized as follows. The next section describes the survey design, implementation, and its outcomes. This is followed by the development of discrete choice models to analyze traveler attitudes to an ODAS. Then, the models are analyzed, and study insights, limitations, and policy implications are discussed. Finally some concluding comments are presented.

2. Survey description and outcomes

A discrete choice model based on random utility maximization is used to determine the probability of switching from the current preferred intercity travel mode to an ODAS. Hence, a binary choice model is developed to analyze the viability of the new ODAS mode. The utility functions are constructed using the choice attributes and data collected through the SP survey.

2.1. Survey mechanism and issues

As the ODAS mode is currently in its infancy, a revealed preference (RP) survey approach is not an option. An SP survey through an on-site questionnaire was used to elicit the traveler attitudes to a new ODAS for intercity travel. The SP method allows the researcher to control the explanatory variables (Kroes and Sheldon, 1988) and provides capabilities to understand the respondent preferences to a range of plausible values (obtained from market analyses and business models) for key choice attributes. As is well known, the SP methodology has limitations; primarily, that subjects may not respond in a real situation the way they indicate in the survey. Also, given the novelty of ODAS, respondents may not have a good "feel" for this service beyond the compact description provided on the survey form. That is, they may not have past experience with a similar service, and would convey their perceptions primarily through their responses to survey questions. This puts a premium on the specific set of questions asked in the survey questionnaire, and indicates another issue with an SP survey: the possibility of a lengthy survey to understand the influence of key variables. Ideally, it would be desirable to elicit traveler preferences for several specific choice scenarios, but that implies a very long survey questionnaire. Hence, in our survey, we use insights from market analyses (Lewe et al., 2006; Cooke et al., 2005; Lewe, 2005) to identify ranges for key attributes (such as fare, travel distance, etc.) so as to limit the number of questions asked.

Another survey issue relates to the market segments that must be tapped to understand the possible evolution of ODAS over time. In the short-run, it is more likely that high-income individuals and business travelers would avail of the ODAS mode. The long-tern evolution of ODAS depends on several aspects ranging from short-term performance, technological advances that further reduce cost, government policies, private sector business models, and the long-term attractiveness of current intercity travel modes. Hence, under a set of favorable circumstances, the widespread use of ODAS is a possibility. The survey should ensure adequate representation from the high income groups and the general population, respectively, to address the short-term and long-term trends.

2.2. Survey design and implementation

The survey consisted of a cover sheet and two pages of questions. The cover sheet described the ODAS in terms of service characteristics, accessibility, and aircraft characteristics to provide respondents with a basic notion of the ODAS mode. The questions resided in two sections: (i) questions that capture the socioeconomic characteristics in terms of gender, age, level of education, and household size, and (ii) questions that seek information on factors considered for intercity trips, the choice of modes, and the possibility of switching to an ODAS under various conditions. In this latter part, respondents were provided information on trip purpose, and ranges of trip distance and cost, and asked if they would switch to an ODAS from their usual preferred mode. The objective in these questions was to determine the influence of different levels of distance, cost, and trip purpose, on the travelers' propensity to switch to and ODAS. Substantial effort was invested in ensuring that the relevant information on preferences was elicited with fewer questions.

The on-site survey method was used to administer the survey. This choice was deliberate as it allowed the researches to elaborate on the ODAS characteristics as well as personally interview the respondents. This enabled respondents to make more informed SP decisions on the ODAS and increased the reliability of the responses.

The generic scenarios in terms of trip purpose and the ranges for trip distance and cost, are discussed hereafter. There are two types of trips based on the purpose: business and personal. The two ranges of distances considered were: trips under 480 kilometers (300 miles), and trips between 480-960 kilometers (300-600 miles). As stated earlier, the 960 kilometer upper limit was chosen based on prior analysis of the future air transportation options. Finally, three ranges for the one-way fare were chosen; these ranges were different for business and personal trips. The ranges for business trips were: \$100-\$150, \$150-\$300, and \$300-\$500. For personal trips, the ranges were: \$50-\$100, \$100-\$200, and \$200-300. They were chosen based on the market analysis findings of Cooke et al., (2005) and Lewe (2005). The determination of the ranges for trip fare and distance is a critical element of the survey design as these ranges significantly affect respondent decisions.

To address the market segment issue discussed previously, and to ensure a broad cross-section of individuals, responses were collected from: (i) a rest area on an interstate freeway (I-65) in the vicinity of the Chicago urban region, (ii) the Navy Pier area of Chicago downtown, (iii) outside the football stadium at Purdue University, West Lafayette, (iv) a few business locations in West Lafayette, (v) a regional airport in Orlando, Florida, and (vi) a few aviation business executives. Together, this provided data on rural and urban travelers, personal and business trips, low income to high income brackets, and those who had auto or commercial airlines as their current preferred mode.

2.3. Survey sample characteristics

Table 1 illustrates the aggregated socioeconomic characteristics of the 372 survey respondents. About 59% of the respondents were males. The distribution of the respondents in terms of age group was mostly even, except for age groups 45-54 and older than 64. A majority (61%) of the respondents had at least some college experience and 54% received at least one college degree. The survey income distribution seems to mirror the U.S. demographic trends, with most people being classified as "middle class".

The respondent willingness to switch to the ODAS under different combinations of trip purpose, distance range, and fare range, is summarized in Figures 2(a) (business trip) and 2(b) (personal trip). They display two consistent trends. First, the willingness to shift to an ODAS reduces as fare increases. Second, the propensity to switch increases with distance. Both trends are consistent with travel behavior. For longer trips, the ODAS is perceived to provide more flexible, comfort and/or convenience compared to auto or scheduled commercial air service. A comparison of Fig. 2(a) and Fig. 2(b) suggests slightly greater willingness to switch under personal trips. However, this difference may simply be the artifact of the difference in the fare ranges used for business and personal trips. To some extent, the differences in fare ranges may limit the consistent comparison of the propensity to switch under business and personal trips.

Table 1 and Fig. 2 provide only a limited understanding of traveler behavior in the context of the new ODAS mode. The next section develops discrete choice models to obtain detailed insights.

3. Discrete choice models

3.1. Model structure

The choice set of the individual consists of the current preferred mode and the new ODAS mode. The current preferred mode is identified by the frequency of intercity trips using various modes (commercial airline, auto, business aviation, and other). The choice problem simply focuses on whether the individual would switch from the current preferred mode to the ODAS mode. Hence, a binary logit model is used to predict the probability that a traveler would switch to the new ODAS. Thereby, the probability that a traveler switches to the new ODAS is given by:

$$P_n(i) = \frac{1}{1 + e^{-(V_{in} - V_{jn})}} \tag{1}$$

where i represents the alternative that the traveler switches and j represents the alternative that the traveler does not switch. V_{in} and V_{jn} represent the systematic components of the corresponding utilities for individual n. The difference in the systematic components is represented as follows:

$$V = (V_{in} - V_{jn}) = ONE + \beta X + \alpha ODAS \tag{2}$$

where,
ONE = alternative specific constant corresponding to switching,
X = vector of socioeconomic variables,
β = vector of estimated parameters corresponding to X,
$ODAS$ = vector of explanatory variables related to the new ODAS,
α = vector of estimated parameters corresponding to $ODAS$.

3.2. Switching models

As discussed previously, the survey questionnaire elicited the respondent propensity to switch to the ODAS for: two trip purposes, two trip distance ranges, and three trip fare ranges. Hence, a respondent provides the switching decision for twelve combinations of trip purpose, distance range, and fare range. Based on this data, we build two types of models. The first set consists of twelve single combination switching models, one for each combination of trip purpose, distance range, and fare range. The second set consists of two switching models by trip purpose, one for business trips and the other for personal trips.

3.2.1. Single combination switching models

Twelve switching models are constructed. The dependent variable is whether there is a switch or no switch to the ODAS from the current preferred mode. The explanatory variables include the socioeconomic variables and those related to the new ODAS. The advantage of these models is that the raw survey data can be directly used without requiring any transformation. Further, they factor three key decision-making attributes (trip purpose, distance, and cost) in a transparent manner. Hence, these models have robust explanatory power. However, they may have different subsets of explanatory variables. Table 2 describes the set of explanatory variables that were found to be significant in one or more of these models, analyzed in Section 4.1.

3.2.2. Trip purpose switching models

Two switching models based on trip purpose are constructed. The six switching decisions of a respondent for personal trips are used for constructing a single personal trips switching model. Similarly, a business trips switching model is developed using all six business trip switching decisions of each respondent. The dependent variable is identical to that for the single combination switching models; whether to switch or not switch to the new ODAS. However, unlike the single combination switching models, cost is now an explicit explanatory variable. This is done by creating a new independent variable related to cost, which is defined as the difference between the fares of the current preferred mode and the ODAS; it implies the need for information on the fare for the current preferred mode. There is no explanatory variable added for distance as it is common across the two alternatives.

An advantage of these switching models is that only two models are required, business and personal. Also, it may allow extrapolation to new levels of cost (fare). However, as the six decisions for each respondent are pooled, their disturbance terms are correlated due to the common unobserved factors introduced by the same respondent providing these responses. Ignoring this issue can result in erroneous model parameters and the overestimation of the t-statistic (or P-value). To address this, a random correction of the disturbances is introduced to eliminate the correlation among the responses. Thereby, a random effects binary logit specification is used to estimate these two switching models. The random effects model has a random constant term, whereby a random component is added to the constant term during the estimation phase to eliminate possible correlation across the disturbance terms.

Further, these switching models need information on the travel cost of the current preferred model of intercity transportation. Since this question is not easily answerable in a survey (it is dependent on the specific trip in terms of the origin, destination, and time of the year), it was estimated using the following equation, a commonly-used method to estimate commercial airline fare as a function of distance (Lewe, 2005):

$$Fare = \sum_{i=0}^{2} \alpha_i D^i \qquad (3)$$

where D is the one-way distance (in miles), $\alpha_0 = 86$, $\alpha_1 = 1.77 \times 10^{-1}$, and $\alpha_2 = -2.46 \times 10^{-5}$.

As illustrated by Equation (3), the fare computation here is only for the commercial airline alternative. Hence, for the trip purpose switching models of Section 4.2, it is assumed that commercial airline is the only alternative to the new ODAS. However, if the appropriate data is collected, the current preferred mode need not be limited to the commercial airline option.

Table 3 describes the set of explanatory variables that were found to be significant in one or both of these models, discussed in Section 4.2.

4. Model analysis and insights

The LIMDEP software (Greene, 1998) was used to estimate the parameters of the discrete choice models. As stated earlier, the insignificant variables of the intermediate models were omitted, leading to the explanatory variables described in Tables 2 and 3. Some variables in these tables (OLD, OLDER, HIGHED, HIGHINED) were obtained after analyzing different combinations of aggregation of the corresponding ranges.

4.1. Single combination switching models

Tables 4 and 5 illustrate the estimated models for business and personal trips, respectively. As discussed earlier, note that different cost ranges are used for business and personal trips based on marketing estimates. The analysis suggests some trends that are common to these models and others that are not.

4.1.1. Socioeconomic variables

The models suggest that age (OLD or OLDER) is an important explanatory variable for business and personal trips. In all instances, OLD and OLDER have negative coefficients, indicating that older individuals are more likely to continue their habitual mode of intercity transportation. This is because older individuals are less likely to shift from a familiar mode which they are comfortable with, and are hence risk-averse in that sense. From a cost perspective, it requires a higher age threshold (OLDER) for individuals to resist switching at lower costs, as illustrated by the significance of OLDER for the lowest price range and that of OLD for the higher price ranges. That is, lower costs reduce the sensitivity to age in terms of switching to an ODAS.

The level of education (HIGHED) is a key factor for business trips and has a positive coefficient. Well-educated individuals exhibit a greater tendency to switch to an ODAS compared to their less-educated counterparts since their jobs are more likely to require efficient intercity transportation with less flexible schedules. Another aspect related to education is the level of acceptance of new technology. Well-educated individuals are likely to be at greater ease with technological innovations, at least initially, and hence may not exhibit as much *a priori* inertia to switching modes. Another trend, akin to that for age, is the lack of sensitivity to education when costs are low ($100-150).

The level of education is largely an insignificant explanatory variable for personal trips. It illustrates the interaction between cost and the operational distance for the ODAS. Personal automobile is the predominant mode for personal intercity travel involving relatively moderate distances; it provides schedule flexibility while being cost-efficient. Hence, the specified ODAS travel costs may not be attractive for personal trips, especially as household size increases. Also, the cost ranges for personal trips are lower than those for business trips, reducing potential sensitivity to education levels. However, if the ODAS costs reduce in the long-term, the significant doorstep-to-doorstep time savings afforded by it may generate education/income sensitivity.

4.1.2. Mode-specific variables

Variable ONE is the alternative specific constant. It represents the utility of the usual preferred mode of intercity transportation for an individual when all explanatory variables take zero values. A positive sign implies an inherent tendency to take the usual preferred mode. For business trips, this coefficient is positive for all six models implying that to induce switching ODAS needs to provide convincing benefits over the alternate modes of intercity transportation. A clear trend is that as the ODAS price range increases (for the same distance range), there is an increasing inclination towards the current preferred mode. Another consistent trend is that for the same price range, there is a higher inclination for the current preferred mode when the travel distance is smaller. This is intuitive, and implies that the appeal of ODAS increases as the travel distance increases because the doorstep-to-doorstep time savings increase substantially. The first trend is also observed for personal trips; increasing costs reduces the appeal of ODAS. Due to the lower low price range ($50-$100) for personal trips, there is an *a priori* tendency to favor ODAS over the usual preferred mode (negative sign for ONE), possibly due to the significant time savings.

The models also indicate that the accessibility to ODAS is an important factor, as illustrated by the significance of several location variables (LOCAT) which take positive values. For business trips under all cost ranges, individuals are more likely to switch to the new ODAS if it has an air portal close to their place of work. For the lower cost ranges, they are also inclined towards the ODAS if it is available in small and major airports. Interestingly, the availability of the ODAS close to their neighborhood (LOCAT1) does not necessarily persuade individuals to switch to it for business trips, suggesting that proximity to the work location enhances the efficiency of time use for business purposes rather than intruding into their personal time. This aspect can be especially important for individuals with long work commutes.

For personal trips, under most scenarios, individuals are more likely to switch to the new ODAS if it has an air portal close to their neighborhood, their place of work, or small and major airports. Given that personal trips have lower cost ranges, locational convenience seems to represent a major incentive for ODAS use. Further, in all such cases, the coefficient for small airports (LOCAT4) is larger than that for major airports (LOCAT3), suggesting that users see a higher incentive in having the service at small airports. This is intuitive because smaller (local) airports are typically more proximate and do not incur the traffic congestion delays in the vicinity of major airports. Further, they circumvent the operational queuing delays due to larger volumes of passengers and the air traffic congestion associated with major airports. In all cases, individuals are indifferent to ODAS portals located in transit stations.

The models also indicate that individuals who feel safe flying in small airplanes (55 % of the respondents), both jet and propeller (BOTHAIRP), are more likely to switch to the new ODAS. Similarly, individuals who are more likely to use the new ODAS for both personal and business trips (BOTHPURP) are more likely to switch to the new ODAS. These results are intuitive. Individuals who feel comfortable flying in small and different types of planes are expected to be more attracted to the ODAS, at least initially, than individuals who do not feel comfortable flying in these types of planes. Further, individuals who will use ODAS for both business and personal trips are strongly attracted to ODAS, and are hence more likely to switch to ODAS compared to those who will only use ODAS for business or personal trips, but not both.

4.2. Trip purpose switching models

The two trip purpose switching models were estimated using a random effects binary logit specification. The six responses corresponding to the trip purpose for each individual were used to generate 2232 data points for each model (372*6 = 2232). Table 6 presents the estimated models for business and personal trips.

4.2.1. Socioeconomic variables

The models suggest that the combination of education level and income is a moderately important factor in the ODAS choice context for business trips. HIGHINED has a positive coefficient for business trips indicating that well-educated individuals with high incomes exhibit a greater tendency to switch to the ODAS. This is because higher income individuals value time more, and their work-related travel may have lesser schedule flexibility. However, the combination of education level and income is only moderately significant. This may indicate that since job-related travel expenses are typically reimbursed by the employers, the sensitivity to HIGHINED, though present, may not substantial. HIGHINED is not a significant explanatory variable for personal trips. This may be because the cost ranges for personal trips in the survey questionnaire are much lower than for business trips, and the threshold cost range that differentiates attitudes based on HIGHINED may not have been breached.

Akin to the single combination models, income by itself is not significant here as well. To analyze this trend in more detail, the distributions of the percentage of respondents switching to the ODAS across income categories for business and personal trips are shown in Fig. 3. For each income range, the percentages correspond to the number of respondents for that range only. A common trend is that as the cost range increases, the fraction of people inclined to switch to the ODAS decreases. Also, in the population, a higher percentage of individuals prefer to switch to the ODAS for personal trips compared to that for business trips. This is because the cost ranges for personal trips are significantly lower. Fig. 3(a) suggests that for incomes beyond \$100,000, there is no perceptible difference in switching attitudes for business trips. Further, individuals with incomes below \$100,000 display similar switching attitudes for business trips. For personal trips (Fig. 3(b)), as observed earlier, the sensitivity to income is not pronounced possibly due to the lower and narrower cost ranges. There is a weak trend of increased switching propensity for personal trips for the lower cost ranges for income levels below \$100,000. Also, the distribution of respondents across income categories is representative of the general population. However, it may be useful to analyze the attitudes of a larger sample of the high income individuals as the ODAS may be targeted, at least initially, to this market segment.

4.2.2. Mode-specific variables

ALPHA is the alternative specific constant, and reflects the *a priori* propensity to switch to the ODAS when all explanatory variables take zero values. Hence, its positive values for both business and personal trips imply a natural tendency to switch to the new ODAS. By contrast, the single combination switching models mostly indicated an *a priori* inclination towards the current preferred mode. Given that the trip purpose switching models include cost as an explanatory variable unlike the single combination models, the relative advantage of time savings for intercity transportation obtainable through the ODAS increases its appeal. The cost variables (DIFCOSTB and DIFCOSTP) are significant and have negative coefficients, indicating that increased costs reduce the likelihood of switching to the ODAS. This consistent trend of the effects of cost suggests that the ODAS fare pricing is a fundamental determinant of the relative attractiveness of an on-demand air service. Another consistent trend is the importance of the accessibility to ODAS for both business and personal trips. As illustrated in Table 6, individuals are more likely to switch to an ODAS if its air portals are located close to their job location (LOCAT2).

4.3. Policy insights

The analysis of the models provides some important broader insights that illuminate policy considerations and guide further study directions. From an operator business model perspective, it appears likely that the price point differentiator has not been reached within the service fare ranges used in the survey, since switching percentages were at best weakly sensitive across income categories. This finding is valuable in determining lower bounds on pricing for operators. Future investigations should experiment with expanded ranges in the upper end in order to locate the point at which price significantly impacts the switching probability for the relevant income categories.

The significance of the location variables (LOCAT) indicates that the location of the ODAS portals should be a key consideration for the ODAS mode. In most instances, individuals are more likely to switch to the ODAS if its air portals are close to people's work location, at major airports or at small airports. In all cases, individuals are indifferent to switching if the ODAS portals are located at transit stations. Hence, the ODAS service portal location access represents a crucial consideration to be dealt with by operators and planning policy-makers. From an operator policy standpoint, it suggests that locations of new portals close to large industrial zones may be beneficial in terms of generating consistent demand, or conversely, it makes good business sense to locate new businesses in the proximity of small- to medium-sized airports in rural areas. It also indicates the possibility of incompatibility between community planning considerations and the needs of ODAS operators; environmentally motivated restrictions on the level of access to ODAS may render the service economically non-viable. Further analysis of switching behavior with explicit mention of environmental impacts could be useful in this regard.

Finally, some limited but important insight into customers' attention on safety and travel experience is obtained. The survey results indicate a comfort level with small aircraft that is a positive indicator of the willingness to switch to ODAS. However, this positive feeling will be in jeopardy if a significant number of accidents occur during early ODAS operation. Therefore, these factors will continue to be key inputs for the design of very light jets and the regional airspace systems in which they fly. This topic is especially timely as the air transportation community is seeking to revamp the airspace system into what is called the Next-Generation Air Transportation System (NGATS) (JPDO, 2004). Further, a widely successful introduction of ODAS operations will likely help alleviate demand for operations at large hub airports but will also place a new requirement on the airspace management in currently "quiet" regional areas.

5. Concluding comments

This study presents traveler behavior models that analyze user propensity towards a new VLJ-based on-demand air service, with the broader objective of providing guidance for the enabling stakeholders including business operators, policy-makers and aircraft manufacturers. The models predict the probability of individuals switching from their usual preferred mode of intercity transportation (up to 960 km) to the ODAS under a range of scenarios in terms of travel distance and cost. On-site SP surveys were conducted across Indiana, Illinois and Florida to generate the data for model development.

The study suggests travel distance, service fare, and the ODAS location as key factors influencing user switching decisions. The doorstep-to-doorstep travel time savings under ODAS increase with distance, making it a more attractive mode for moderate-distance intercity trips. This is further reinforced by the additional comfort generated by avoiding long auto trips, especially through congested urban areas. This has implications for the ODAS operators in designing their operations network to be economically sustainable, as well as for aircraft manufacturers in terms of design factors to consider while developing more efficient VLJs. In terms of service fare, while there is a clear preference for the ODAS in several scenarios, the fare ranges need to be carefully determined by business operators to achieve the desired market share. The consequent price points provide further inputs to aircraft manufacturers on target cost ranges of future VLJ designs, both in terms of product costs and maintenance needs.

ODAS location is a key determinant of its operational viability, and has significant implications for policy-makers, regional/city planners, operators, and businesses. While ODAS proximity to work is an attractive attribute for users, environmental concerns can arise if it is close to residential areas. This provides further inputs for future VLJ designs in terms of acceptable noise levels. It also provides directions on regulatory oversight for regional planners. Further, the insights on the importance of location provide pointers for ODAS operators on where to locate such services, and for businesses to identify potential locations in rural areas. Hence, ODAS can have implications for regional economic development.

At a holistic level, ODAS has the potential to mitigate the ever-rising congestion concerns at major airports, while spawning new operational paradigms that focus on point-to-point regional on-demand air transportation service. The resulting new air traffic network patterns have fundamental implications for the evolution of the air traffic control systems under NGATS. Also, there may be consequent needs in terms of updating the infrastructure in the vicinity of local airports to increase accessibility to the ODAS service and ensure robust performance of the associated surface transportation system. Further, in the long-run, there can be modal shifts in the traffic patterns in the multimodal transportation system of a region due to an ODAS. Ultimately, it can lead to the era of personal aviation.

In summary, the potential advantages of an ODAS include significant doorstep-to-doorstep trip time savings for travelers, congestion mitigation at commercial airports, and the level of accessibility offered by thousands of underutilized local airports from which ODAS can operate. Potential barriers include unsustainable business strategies, operational costs, environmental (noise) concerns, and traveler perceptions of very light jets from a safety standpoint.

The need for greater clarity concerning the viability of ODAS also stems from a broader NASA-sponsored study undertaken by the authors (DeLaurentis and Han, 2006). Its objective is to understand the possible pathways to transformation of air transportation over the next 25 years in a manner that meets future demand while minimizing delay and fragility of the system. Through the use of a system-of-systems methodology employing agent-based modeling and network science, alternate economic, regulatory, and technical decisions are being examined at the holistic level to uncover the key patterns that could guide action towards more efficient air transportation. The possible emergence of ODAS must be accounted for in a subset of these future scenarios, and thus the import of the switching models for ODAS described in this paper.

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Table 1
Socioeconomic characteristics (372 samples)

Attribute	Range	(%)
Gender	Male	59.2
	Female	40.8
Age Group	<25	12.8
	25-34	15.0
	35-44	16.6
	45-54	26.7
	55-64	18.5
	>64	10.4
Education Level	High School or Less	17.2
	Some College	28.6
	College Graduate	31.9
	Post Graduate	22.3
Income	Less than $30,000	18.5
	$30,000-$59,999	26.1
	$60,000-$99,999	30.5
	$100,000-$150,000	15.7
	More than $150,000	9.2

Table 2
Explanatory variables for single combination switching models

Explanatory Variable	Mnemonics
Alternative specific constant for not switching from current preferred mode	ONE
Age group: = 1, if age ≥ 40 years = 0, if age < 40 years	OLD
Age group: = 1, if age ≥ 55 years = 0, if age < 55 years	OLDER
Level of education = 1, if education > some college = 0, if education ≤ college	HIGHED
Individuals who will use the new ODAS if it is available close to their neighborhood = 1, if yes = 0, if no	LOCAT1
Individuals who will use the new ODAS if it is available close to job location = 1, if yes = 0, if no	LOCAT2
Individuals who will use the new ODAS if it is available at major airports = 1, if yes = 0, if no	LOCAT3
Individuals who will use the new ODAS if it is available at small airports = 1, if yes = 0, if no	LOCAT4
Individuals who from a safety standpoint feel comfortable flying in small airplanes (jet or propeller) = 1, if yes = 0, if no	BOTHAIRP
Individuals who are more likely to use the new ODAS for both personal and business trips = 1, if yes = 0, if no	BOTHPURP
Individuals who will consider moving their home or choosing to work at a distance of 0-32 kilometers away if the new ODAS is available for daily commuting = 1, if yes = 0, if no	MOVEDIS1

Table 3
Explanatory variables for trip purpose switching models

Explanatory Variable	Mnemonics
Alternative specific constant for switching to ODAS	ALPHA
Level of education and income = 1, if education > some college & income ≥ $100,000 = 0, if education ≤ college & income < $100,000	HIGHINED
Difference in cost between taking the new ODAS and taking commercial airplane for a personal trip	DIFCOSTP
Difference in cost between taking the new ODAS and taking commercial airplane for a business trip	DIFCOSTB
Individuals who will use the new ODAS if it is available near the job location = 1, if yes = 0, if no	LOCAT2

Table 4
Single combination switching models for business trips

Distance(km)	0 - 480		0 - 480		0 - 480		480 - 960		480 - 960		480 - 960	
Cost ($)	100 - 150		150 - 300		300 - 500		100 - 150		150 - 300		300 - 500	
Variable	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics
ONE	0.8704	3.301	1.6392	5.716	2.4868	6.977	0.1367	0.594	0.7193	2.817	2.2141	7.223
BOTHAIRP	0.4978	1.808					1.4155	3.452	0.8897	3.7		
BOTHPURP	1.6309	3. 768										
LOCAT2	1.1206	3.589	0.9394	4.036	0.58	1.81	1.1601	3.661	0.429	1.902	1.0476	3.833
LOCAT3	1.0259	3.69	0.658	2.874			0.6078	2.278	1.2559	5.44		
LOCAT4	0.8487	3.014					1.4198	5.151				
MOVEDIS1	1.4198	4.093	0.6199	2.473								
HIGHED			0.7498	3.183	0.8399	2.425			0.3849	1.708	0.8043	2.797
OLD			-0.6432	-2.759	-0.5861	-1.814			-0.9028	-3.865	-0.4643	-1.704
OLDER							-0.8853	-3.179				

Table 5
Single combination switching models for personal trips

Distance(km)	0 - 480		0 - 480		0 - 480		480 - 960		480 - 960		480 - 960	
Cost ($)	50 - 100		100 - 200		200 - 300		50 - 100		100 - 200		200 - 300	
Variable	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics
ONE	-0.2548	-1.131	0.683	3.028	2.3533	9.105	-0.203	-0.71	0.9505	4.567	1.0785	5.31
OLDER	-0.7194	-2.639					-0.5904	-2.035				
OLD			-0.6656	-3.057							-0.3954	-1.724
HIGHED							-0.6851	-2.477				
LOCAT1	1.0001	3.671					0.7531	2.635	0.5166	2.236		
LOCAT2			0.6739	3.017	0.5973	2.114	1.2425	3.573	1.1852	4.692		
LOCAT3	0.9045	3.315	0.4932	2.309	0.7131	2.48	0.7731	2.719	0.5362	2.363		
LOCAT4	0.9694	3.574	0.5816	2.653			1.5841	5.312	0.9159	4.041	0.4784	2.062

Table 6
Trip purpose switching models

Variable	Model			
	Business		Personal	
	Coefficient	P-value	Coefficient	P-value
ALPHA	0.387627	0.0177	0.773112	0.0000
DIFCOSTB	-1.46E-02	0.0000		
DIFCOSTP			-1.38E-02	0.0000
HIGHINED	0.50517	0.0669		
LOCAT2	0.506757	0.0251	0.652251	0.0053

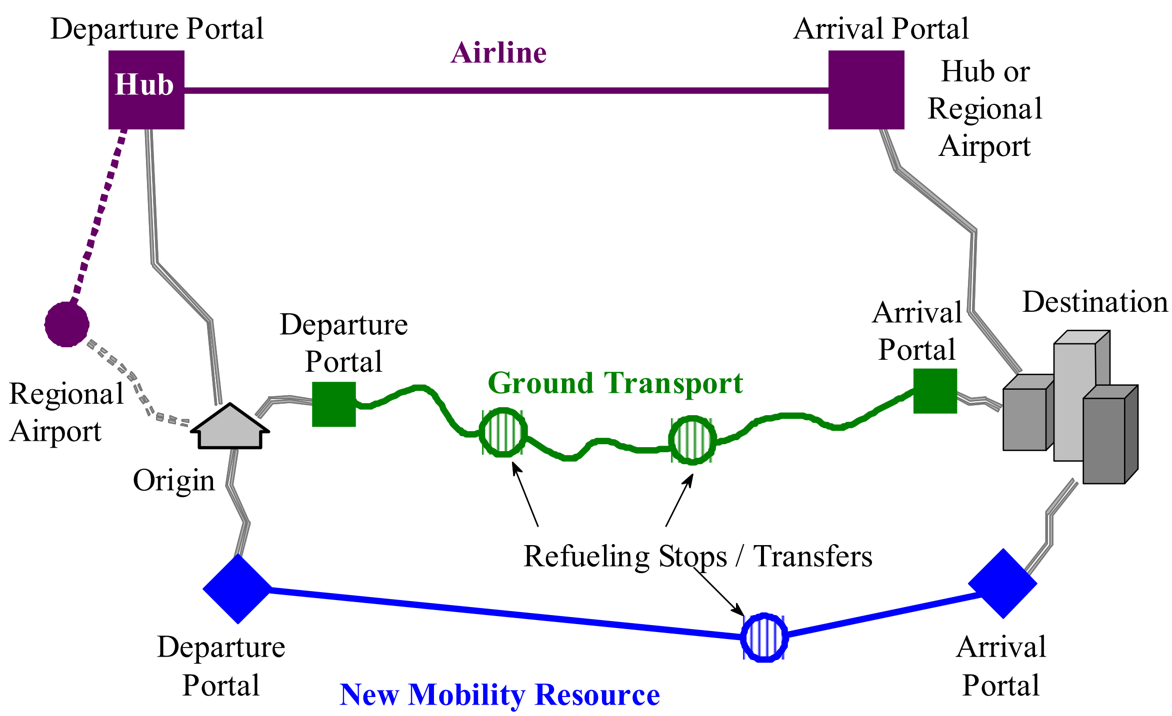

Fig. 1. The generic doorstep-to-doorstep trip.

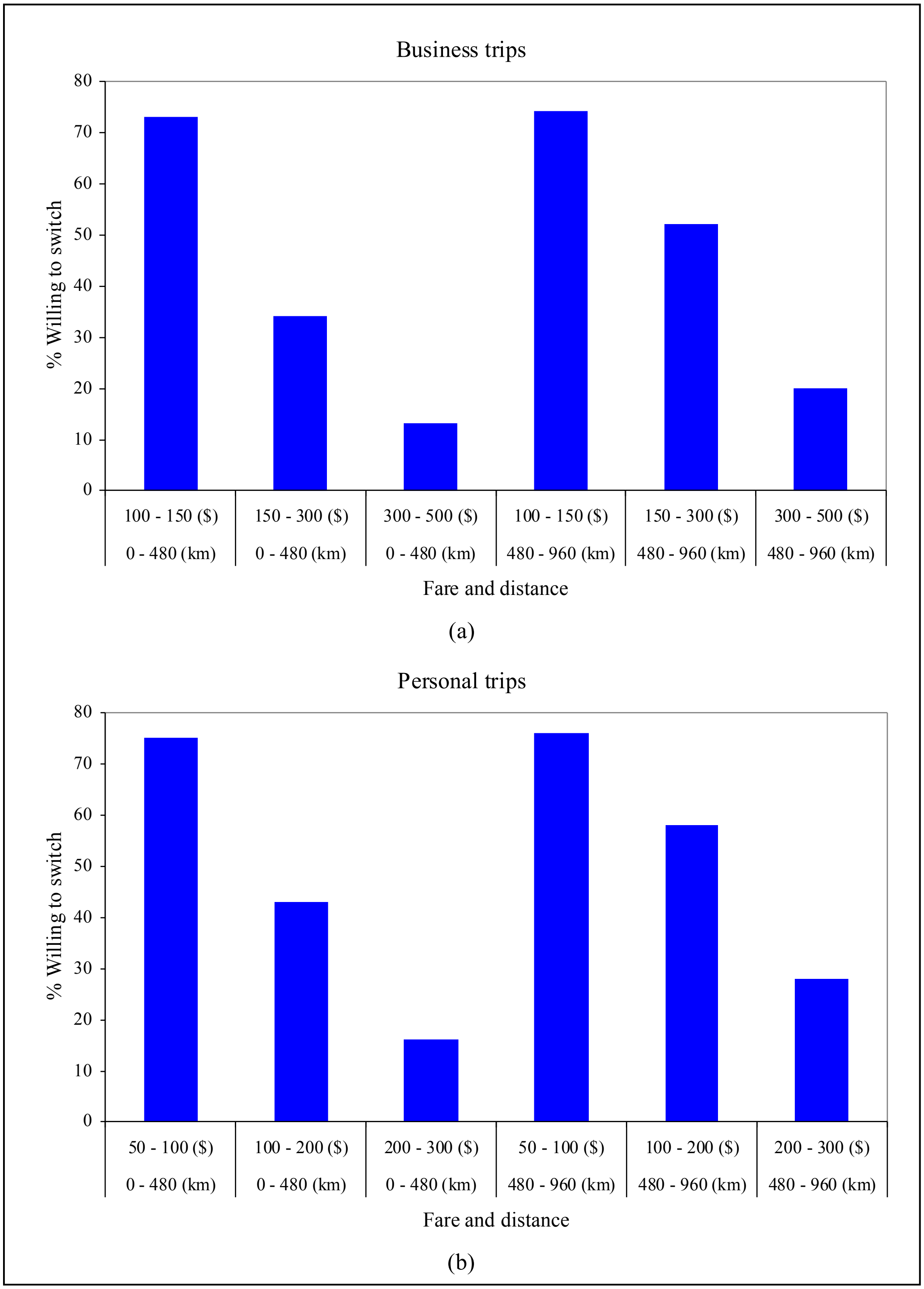

Fig. 2. Individual willingness to switch to the ODAS: (a) business trips, (b) personal trips.

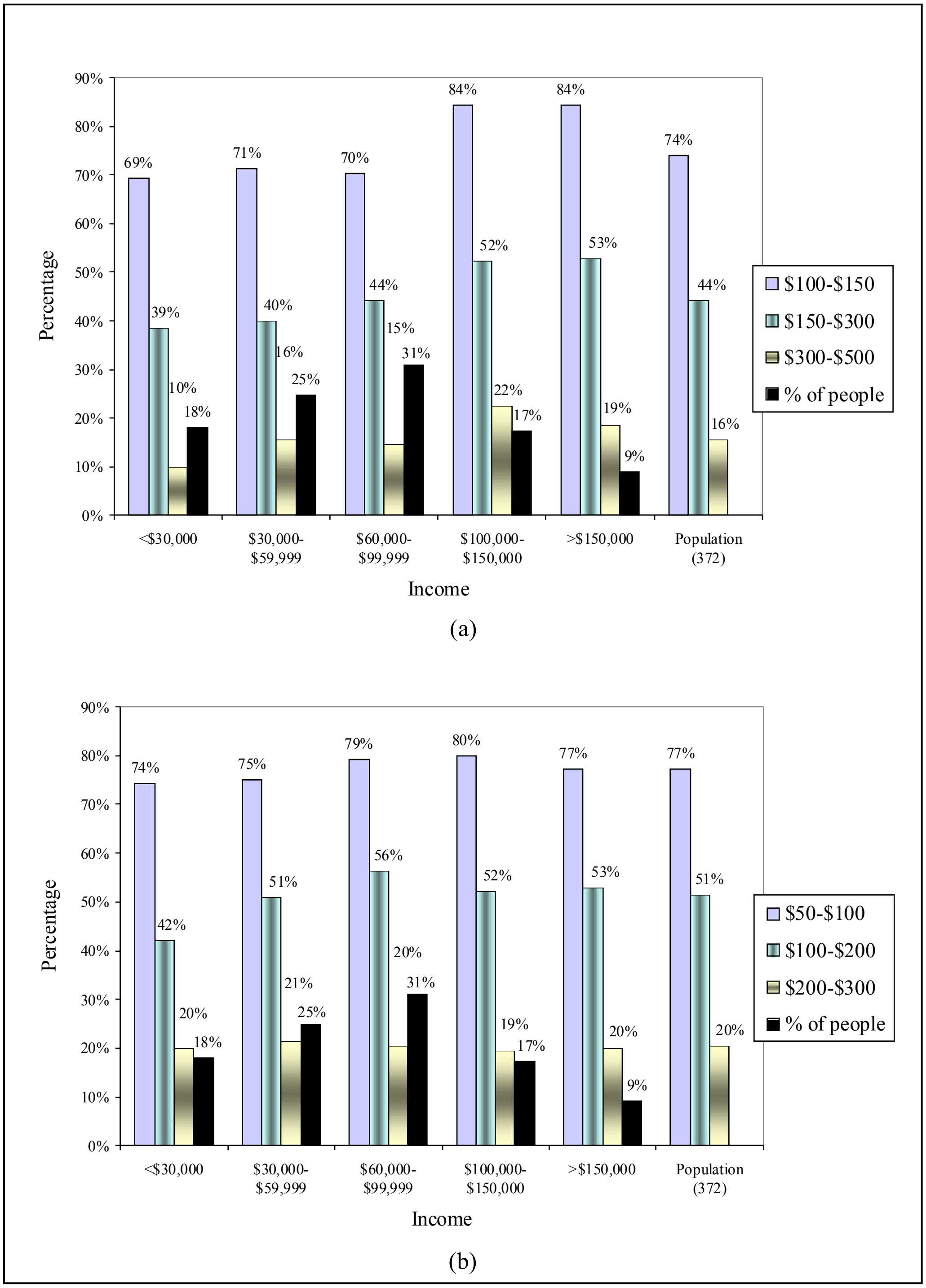

Fig. 3. Percentage of respondents switching in each income category: (a) business trips, (b) personal trips.