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INTEGRATIVE TECHNOLOGIES TO SUSTAIN DIAL-A-RIDE SERVICES

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Abstract

Today's ageing population has put a lot of pressure on the demand for dial-a-ride services, not only for the elderly, but also for people with disabilities. However, with the limited increase of social expenditure across many countries and the low utilization vehicle characteristic of the operations, the traffic demand of community transportation services for those needy people would not be satisfied in the future. This paper aims to investigate how the integrative technologies of vehicle scheduling system and geographic information system can support the new sustainable operational model for the dial-a-ride services. According to the experiment evaluation, the integrative technologies of geographic information system and scheduling optimization system can provide the opportunity of serving additional people without the increase of vehicles.

Keywords: dial-a-ride service, geographic information system, vehicle routing

1. Introduction

In the decades of ageing population, many governments and community organizations paid new attention on the social welfare spending. The United Nations [1] projected the proportion of people aged above 60 to reach 22% by 2050 in comparison to 10% in 2000. However, the Organization for Economic Co-operation and Development (OECD) [2] also reported the decline of public social spending-to-GDP ratio to 21.6% in 2014 while that ratio was 22.1% in 2009. It was challenging for community organizations to sustain their operations for the increased demand of people withthe limited increase of government subsidy. This research investigated an innovative and sustainable operation to providedial-a-ride (DAR) services for the people with disabilities and the elderlies. With the emergent information technologies for open access, community organizations could make use of the advanced technologies to provide innovative transportation services for the needy people.

This paper aims to investigate how information technologies can lead to a new dial-a-ride service with the service option, which would allow some of the passengers who ride in a vehicle with others to receive a discount rate but may need to tolerate a longer traveling time. In comparison to the bus services, dial-a-ride services are designed for people who require door-to-door and on-demand travel without regular traveling schedules. This results in the low vehicle utilization rate which would be managed by increasing the fare price in the business sector. However, for the community services, the fare price also needs to be affordable by the needy people. Dial-a-ride servicestherefore require a higher subsidy than the other transportation services in general. To address the low vehicle utilization issue, we will investigate the new service option of shared dial-a-ride (SDAR) by the integrative technologies of geographic information systems and vehicle scheduling systems.

This paper is organized as follows. Section 2 will be the related work. In section 3, we will describe the shared dial-a-ride operations with the integration of information technologies. The experiment evaluation will be conducted in section 4. Finally, section 5 will be conclusion.

2. Related Work

For the research study in sustainable operations, the related works in literature were spanned by two areas. The first research area was related to the resource control in revenue management. Inventory problems were commonly studied for various applications which were summarised by McGill et al. [3]. To differentiate multiple customer request priorities, the rationing policies of determining a threshold level were commonly studied [4-7] for the revenue management of before-sale products. For the study of after-sale services, Mo et al. [8] evaluated the spare part support services for two types of users who were classified by standard and premium contracts. This paper also studied two types of users who could be classified by their service preferences of fare discount and additional travelling time tolerance. Another related research area was related to the vehicle routing problems. Due to the high complexity of problem nature, heuristics [9-14] were considered. Within those classes, a few researchers [13, 14] studied multiple objectives criteria. There was a lack of research on maximising the total number of served users by simultaneously optimising the request order revenue and vehicle resources. This differed from the classical DAR problems, this paper investigated the multi-objectives of minimising total traveling costs for operational efficiency and maximising the total number of people served with the support of geographical information systems to sustain the dial-a-ride service for the elderly and the people with disabilities.

3. Shared Dial-a-Ride Operations

The objective of shared dial-a-ride operations is to maximize the overall traveling performance, including the number of trips and the utilization of vehicle while minimize the operational cost at the same time. To achieve such optimal objectives, it requires an advanced scheduling mechanism which can allocate vehicles with drivers to fulfil the requirement of each travel service order. For SDAR services, different from door-to-door DAR services, passengers may need to tolerate additional traveling time, due to driving other passengers as well as earlier pick-up time and later drop-off time than the original planned time. On the operational side, drivers may also need to drive longer than the single trip. This may affect their allowable break time. Hence, the scheduling mechanism is the core intelligent part for optimizing the operations.

The requirement of the scheduling mechanism is the major challenge for the large scale operations, due to the high complexity. In terms of optimization technology, the SDAR scheduling problem is regarded as a combinatorial optimization model, in which the amount of possibilities could be huge. For example, there are 4 orders with similar pickup and drop off properties and 5 vehicles with drivers. The scheduling DAR operation is to assign the vehicles to the orders. Suppose that it is required to schedule vehicles for fulfilling the specific order, the maximum number of possibilities is $4 \times 5=20$. However, for the SDAR operation, these 4 orders could be merged or handled as an individual order separately. Hence, the number of possibilities becomes $4! \times 5=120$, 6 times more than that of DAR. This increased number of possibilities has an exponential rate when the number of orders increases. For the typical example of an organization for case study, there are 150 orders and 60 vehicles to be scheduled on a day. The number of possible combination becomes $150! \times 60 = 3.43 \times 10^{264}$. This cannot be

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manually managed. Besides, customers always expect to have the information of the vehicle availability and the fare price immediately when they requesta service. Without the integrative information systems, this will be difficult to be achieved. In addition, the overhead of manual scheduling will delay the service delivery information to the customer. Hence, a computerized scheduling mechanism is the essential component in the SDAR operation. With a computerized scheduling tool, the following benefits would be obtained:

1. The whole scheduling process time is shortened;
2. Customer gets instant response to vehicle availability; and
3. Resource is optimally used.

For the implementation of computerized scheduling mechanism, the initial step is to represent the travel service order from the computer programming perspective such that the additional traveling time can be estimated during the order request stage.

Network representation of a service order

A DAR order could be represented by a node and an arc in the network model. A node is used to represent a pick-up and drop-off point. An arc, connected among two nodes, is used to represent the traveling distance and/or time. The network model could then be extended to represent the DAR operation. Table 1 shows the example of three DAR orders, and Figure 1 represents those orders in the network model.

Table 1: Example of DAR orders

Order	Pick-up Point	Drop-off Point	Pick-up Time	Drop-off Time	Kilometer
1	Building A	Hospital	820	925	28
2	Building B	Hospital	825	940	21
3	Building C	Hospital	845	950	26

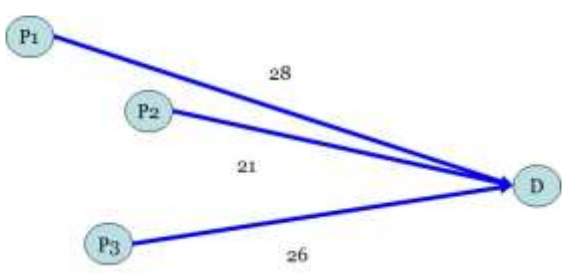

Figure 1a: DAR orders

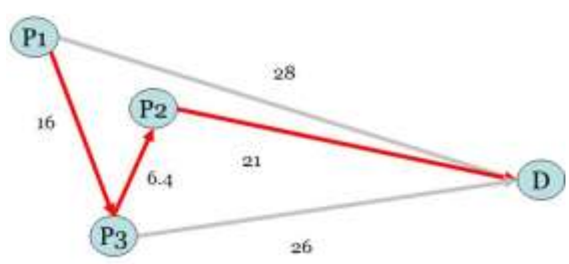

Figure 1b: SDAR orders

For the generic representation, the directed graph $G = (N, A)$ that includes the set of nodes N and the set of arcs A will be considered. Pick-up nodes aredenoted by $P = \{1,\ldots,n\}$ and drop-off nodes are denoted by $D = \{n+1,\ldots,2n\}$. Hence, $N = P \cup D \cup \{0\} \cup \{2n+1\} = \{0,1,\ldots, 2n+1\}$. Each request order $(i, j) \in O$ corresponds to a pair of nodes $(i, n + j)$ with pick-up and drop-off nodes. The start time at node i is denoted as t_i, and each request order, i, will have the time window

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constraint [e_i, l_i]. Then, the service time, the tolerance of additional traveling time and the maximum ride time are denoted as S_i, $\tau$and MRT_i , respectively. i.e.$MRT_i = t_{i+n} - t_i - S_i + \tau$ .The time-dependent DAR scheduling problem with time window constraints is formulated as the mixed integer programming (MIP) model, which can be solved by the optimization technology. However, the solution time could be very long when the problem size is large. In this paper, we will discuss an efficient algorithm in the later session.

To operate the shared dial-a-ride service effectively with the optimization technology, it is crucial to determine the fare price smartly. On one hand, the price needs to be attractive for users selected SDAR instead of door-to-door DAR. On the other hand, the price also needs to cover the operational cost for the sustainable operations. With the geographic information systems, the fare price can be determined immediately during the order request stage.

Fare determination by geographic information systems

The price of DAR service is usually a variable price per use, and it is calculated on a number of factors including the number of passengers, the traveling distance and time, administration costs etc. For instance, Table 2 shows the fare price of DAR service from a non-profit organization.

Table 2: Pricing structure of DAR service

Price	1-3 passengers	4-12 passengers	13-30 passengers
Each hour	$24	$38	$58
Each kilometer	$1.2	$1.9	$2.9

Source: Rehabus

According to the price structure of DAR service, it has the minimum hourly charge of $24 if the travelling time is less than one hour. In the network model, this would be regarded as the initial cost for the vehicle from the depot node to the first pick-up node. On top of this minimum charge, passengers would need to pay $1.2 per km for the traveling distance.

In order to facilitate the computerized scheduling system, the geographic information systems would be used to estimate the traveling time between two locations. This information is one of the critical factors for determining the trip price. For the SDAR service, a discount policy based on the door-to-door DAR service could be provided, as it is expected that the SDAR operation could handle more orders by the same operational resource with the integrative technologies.

For the example of four service orders in a day, each passenger would be asked to select the shared dial-a-ride service option with the discount policy of 10%. If all four passengers are willing to share the vehicles with others, Table 3 shows the result of a scenario based on the operational cost of $1 per km and the additional traveling time of 20 mins for the pick-up point (PP), the drop-off point (DP), pick-up time (PT) and drop-off time (DT).

Table 3: An example of SDAR orders

Order	PP	DP	PT	DT	Cost	Vehicle	Price	SDAR Vehicle	SDAR Cost	SDAR Price
i	1	6	10:00	11:00	$29.2	A	$51.1	A	$50.0	$46
ii	4	5	10:30	11:00	$32.1	B	$45.8			$41.2

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iii	2	8	14:30	15:20	$30.6	C	$43.0	B	$31.9	$38.7
iv	3	7	14:00	15:30	$24.2	D	$38.6			$34.7

Accordingly, the original operation cost is $116.1 and the revenue of fare is $178.5. This results in the gross profit of $62.4. With the 10% discount for all users, the revenue of new fare becomes $160.6. At the same time, due to the operational efficiency by scheduling technology, the operational cost is also reduced to $81.9. This results in the gross margin of $78.7 which is even higher than the original one. In addition, vehicle C and vehicle D can be allocated to serve other passengers.

With the integrative technologies of geographic information systems and the scheduling system, the arrangement of SDAR service could be confirmed and visualized immediately for the operators and users. Figure 2 shows the route visualization of SDAR by the GIS.

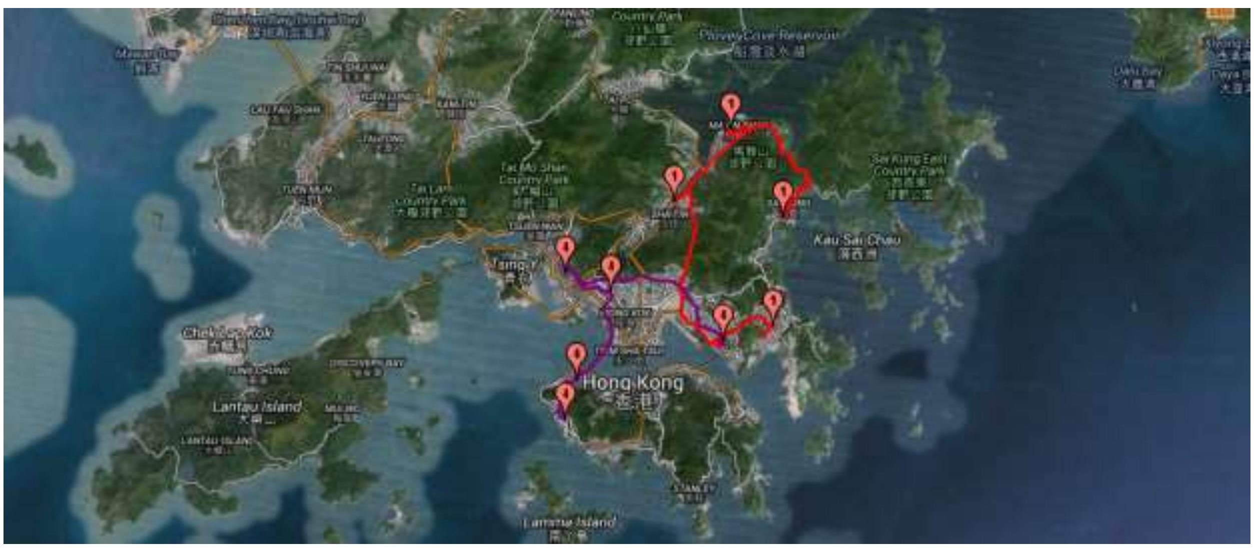

Figure 2:The visualization of SDAR service by GIS

The geographic information systems provide the information to determine fare price and to visualize the SDAR service content. To enhance the efficiency of SDAR, it is critical to optimize the decisions of merging orders such that the number of orders per trip could be maximized while the total traveling time of each trip could be minimized.

Computerized scheduling mechanism

Our design of computerized scheduling mechanism requires the input information from GIS and the policy of customer and driver tolerance time for the algorithm implementation. To illustrate the mechanism by an example, two orders are selected from the pool of available orders in the database which can retrieve the traveling information from the geographic information systems.

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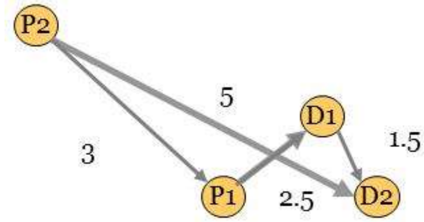

Figure 3: Example of potential merged orders

Figure 3 demonstrates the example of evaluating two orders to be merged.In this example, there are six combinations:{$P_1P_2D_1D_2$,$P_1P_2D_2D_1$,$P_2P_1D_1D_2$,$P_2P_1D_2D_1$,$P_1D_1P_2D_2$, $P_2D_2P_1D_1$} after considered the sequence of order pick-up and drop-off. To enhance the algorithm efficiency, an insertion method is applied. The idea is to insert an order into another order and then evaluate the benefits, as well as the order sequence requirement. With those considerations, the best route of merged orders which can satisfy the customer and driver constraints will be identified by minimizing the traveling distance. For instance, the combination of $P_2P_1D_1D_2$ is being evaluated. Then, from GIS, the traveling information can be obtained and shown in Table 4.

Table 4: Evaluation information from GIS

	Traveling sequence	Distance
Passenger 1	$P_1 \rightarrow D_1$	2.5 km
Passenger 2	$P_2 \rightarrow P_1 \rightarrow D_1 \rightarrow D_2$	7 km
Whole trip	$P_2 \rightarrow P_1 \rightarrow D_1 \rightarrow D_2$	7 km

Afterwards, the set of constraints including driver total traveling time tolerance, passenger earlier pickup time tolerance, passenger drop-off latest time tolerance would be checked. If one of the constraints is not satisfied, the system will then proceed to evaluate another combination. The combination which can satisfyall the constraints will be stored in a pool, namely the potential merging order. Then, the merging order with the minimum traveling time and distance would be selected and stored into another set of "possible merging orders". Figure 4 shows a possible merging order with the best route information for example.

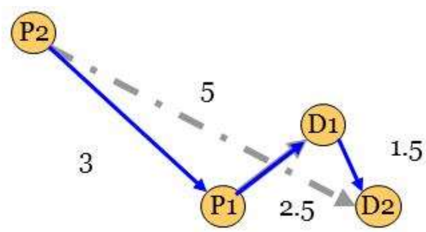

Figure 4: Example of a possible merging order

For the evaluation of that merging order, the parameter of "gain" would be calculated. The gain is used to represent the benefit of such merging combination. It is measured in the difference of total distance divided by the number of orders per a trip. For instance, $P_2P_1D_1D_2$ is the best selected merging order and the total distance of the whole trip is 7 kilometers. Since the original number of orders per a trip is 1 and the total distance is 5 + 2.5 =7.5 kilometers, the original total distance per order ina trip is 7.5 kilometers. For the possible merging order, the number of orders per a trip is 2 and the total distance is 7 kilometers. The total distance per order in a trip is 3.5 kilometers. Hence, the "gain" for such combination is 7.5 – 3.5 = 4. By calculating the "gain" value for the possible merging orders, the saving matrix would be constructed.

Order	1	2	3	4	5
1		4	-3	-3	-4
2		-	-2	-5.5	-4.5
3			--	-2	-1
4				--	6
5					--

Figure5: Saving matrix of merging order

Figure 5 shows the saving matrix of possible merging orders. The first column and row is the index of orders, while the respective box in the table is the gain value of the possible merging orders. If order 1 and order 2would have been merged, the gain value of 4 would be obtained. In case the number of merging order is limited to 2, order 2 cannot be merged with another order. The dotted line indicates the stopping criteria for the merging possibilities of orders. By the greedy algorithm, the merging order with the maximum gain value is selected to be merged. Then, that merged order will be considered for further merging with other others to establish another saving matrix. Repeating the above procedure, the algorithm stops when there is no positive value in the saving matrix.

4. Evaluation and Results

The determination of discount percentage for SDAR servicesis critical for sustaining the operations. It affects the incentives of passengers selecting SDAR services rather than door-to-door DAR, but also impacts on the organizations' financial performance. For the adoption of such shared service, ever organizations need to evaluate the tradeoff relationship among the shared order percentage, given the parameters of passengers' allowable pick-up time tolerance (PTT) and drop-off time tolerance (DTT).

An evaluation experiment was conducted to identify the tradeoff relationship among these three orders based on the real data for the illustration purpose. The parameters of PTT and DTT were set at the minutes of {10, 15, 20, 25} to analyze the shared order%. The shared order % was measured by the number of share orders over the total number of original orders. For example, the total number of original orders was 100. If 10 orders can be merged for SDAR services, the shared order% will be 10%. This index reflected how many vehicles would be released to serve other orders. The algorithm was implemented by Java programming. It evaluated the whole experiment within one minute. The results were summarized in table 6.

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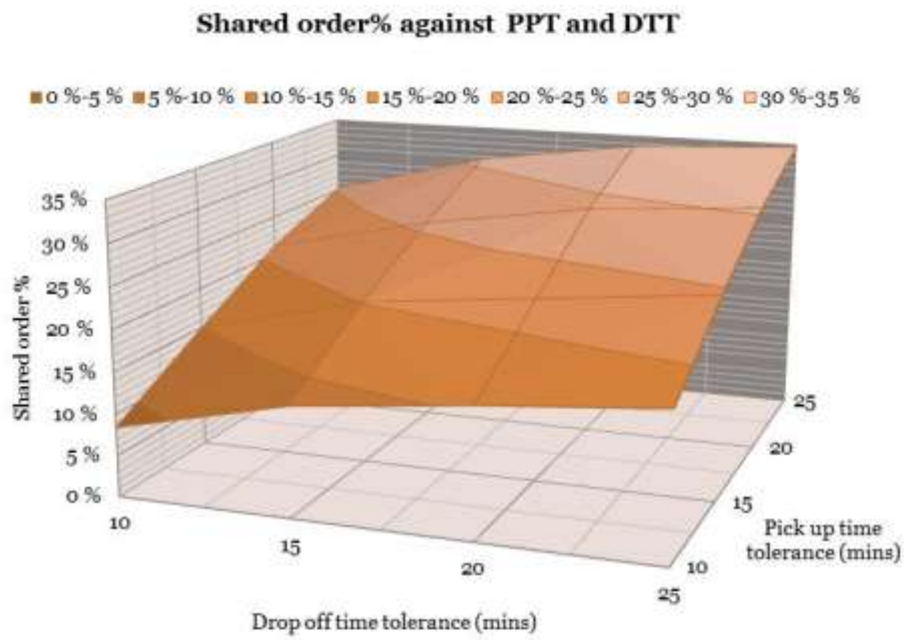

Figure 5: Experiment results of SDAR

Accordingly, it was shown that the minimal value of shared order%was 8.4% and the maximalvalue was 34.7% when the traveling time tolerance increased from 10 minutes to 25 minutes. Theseresults were useful for the organization to determine their discount policy of SDAR and to evaluate their operational performance on the regular basis.

Conclusion

This paper aims to investigate how the integrative technologies of vehicle scheduling system and geographic information system can enhance the sustainability of new operational model for the dial-a-ride services, which face the challenge of low vehicle utilization rate. In the ageing population, the demand of such services substantially increases as the mobility of people with disabilitiesand elderliesreceive a serious concern in the society. By the GIS technology and the proposed optimization algorithm for scheduling mechanisms, shared dial-a-ride services could be promoted for the benefits of both users and organizations. According to the case study of an organization, the experiment results show the opportunities of serving more people without the increase of vehicles. This research results could be widely used in various transportation organizations for the operational and policy review.

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References

i. Chen, S., Xu, J. & Feng, F., 2010. A partial Characterization of the Optimal Ordering/Rationing Policy for a Periodic Review System with Two Demand Classes and Backordering. *Naval Research Logistics*, 57(4), pp. 330-341.

ii. Cordeau, J.-F. & Laporte, G., 2003. A Tabu Search Heuristic for the Static Multi-Vehicle Dial-A-Ride Problem. *Transportation Research B*, 37(6), pp. 579-594.

iii. Deshpande, V., Cohen, M. & Donohue, K., 2003. A Threshold Inventory Rationing Policy for Service-Differentiated Demand Classes. *Management Science*, 49(6), pp. 683-703.

iv. Desrosiers, J., Dumas, Y., Solomon, M. & Soumis, F., 1995. Time Constrained Routing and Scheduling. *In Handbooks in Operations Research and Management Science, Network Routing*. Amsterdam: Elsevier Science, pp. 35-139.

v. Duran, S., Liu, T., Simchi-Levi, D. & Swann, J. L., 2007. Policies Utilizing Tactical Inventory for Service-Differentiated Customers. *Operations Research Letters*, 36(2), pp. 259-264.

vi. Jaw, J., Odoni, A., Psaraftis, H. & Wilson, N., 1986. A Heuristic Algorithm for the Multi-Vehicle Advance Request Dial-A-Ride Problem with Time Windows. *Transportation Research B*, 20, pp. 243-257.

vii. Madsen, O., Ravn, H. & Rygaard, J., 1995. A Heuristic Algorithm for the Dial-A-Ride Problem with Time Windows, Multiple Capacities, and Multiple Objectives. *Annals of Operations Research*, 60, pp. 193-208.

viii. McGill, J. I. & van Ryzin, G. J., 1999. Revenue Management: Research Overview and Prospects. *Transportation Science*, 33(2), pp. 233-256.

ix. Mo, D. Y., Tseng, M. M. & Cheung, R. K., 2014. Design of Inventory Pools in Spare Part Support Operation Systems. *International Journal of Systems Science*, 45(6), pp. 1296-1305.

x. OECD. 2014. *Social Expenditure Update*. Available at: http://www.oecd.org/els/soc/OECD2014-Social-Expenditure-Update-Nov2014-8pages.pdf.

xi. Samii, A. B., Pibernik, R. & Yadav, P., 2011. An Inventory Reservation Problem with Nesting and Fill Rate-Based Performance Measures. *International Journal of Production Economics*, 133(1), pp. 393-402.

xii. Toth, P. & Vigo, D., 1996. Fast Local search Algorithms for The Handicapped Persons Transportation Problem. *In Meta-heuristics: Theory and Applications*. Boston: Springer US, pp. 677-690.

xiii. Toth, P. & Vigo, D., 1997. Heuristic Algorithms for the Handicapped Persons Transportation Problem. *Transportation Science*, 31, pp. 60-71.

xiv. United Nations. 2007. *World Population Ageing 2007*. Available at: http://www.un.org/esa/population/publications/WPA2007/wpp2007.htm.