VISUALISATION OF SOCIO-SPATIAL ISOLATION BASED ON HUMAN ACTIVITY PATTERNS AND SOCIAL NETWORKS IN SPACE-TIME

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ABSTRACT

Few previous studies of socio-spatial isolation have explored both its spatial and temporal dimensions. This study proposes and implemented four visual methods for analysing socio-spatial isolation using graphic representation of people's social networks and activity patterns in space and time: 3D space-time paths, time windows, 3D activity density surfaces, and ring-based visualisation of social networks. These visualisations utilise both activity-travel data and social network information. The data used were collected through a specially designed activity-travel diary survey with a sample of Koreans in the Columbus metropolitan area in Ohio (USA). The results show that these visualisations can considerably enhance our understanding of the relationships between people's activities in space-time and their social interactions. Combining social network analysis with activity pattern analysis can lead to a better understanding of socio-spatial isolation.

Key words: Human activity patterns, space-time paths, social isolation, social networks, visualisation

INTRODUCTION

Socio-spatial isolation of particular social groups in a larger society is a multidimensional phenomenon involving physical, social, emotional, and psychological dimensions (Room 1995; Samers 1998; Saith 2001). But current studies have many limitations for understanding this complex phenomenon. For instance, segregation studies pay more attention to uneven social distribution of groups in a static residential space and less to the isolation resulted from limited social interactions with other people (Schnell & Yoav 2001). This emphasis on residential space is problematic because it ignores variations in socio-spatial separation among different social groups, focusing instead only on the segregation of residential areas (Ellis *et al.* 2004). Further, statistical analyses using census data have considerable limitations in representing social and spatial isolation of specific social groups (Walker 1995), and often mask people's isolation from society (Room 1995; Saith 2001).

While previous studies have made important advances in the analysis of social interactions or social networks using graph-theoretic social network analysis and statistical approaches (e.g. Fischer *et al.* 1977; Wasserman & Faust 1994; Mollenhorst *et al.* 2008a, 2008b), this research

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seeks to contribute to the literature through concepts and visual methods based on the time-geographic perspective (e.g. space-time constraints and space-time paths). Its objective is mainly to develop visual methods for analysing socio-spatial isolation. Although there are various approaches to examining the spatial and temporal characteristics of people's social interactions (e.g. Mollenhorst *et al.* 2008a, 2008b; Grannis 2009; Radil *et al.* 2010), few of them are capable of integrating both the spatial and temporal dimensions when analysing the relationships between space, time and social interactions (Carrasco *et al.* 2007). To accomplish this, this study draws upon the time-geographic perspective and proposes four visual methods for analysing socio-spatial isolation using graphic representation of people's social networks and activity patterns in space and time. It focuses on the relational aspects of socio-spatial isolation as well as variations in people's activities in space and time. It is the first attempt to use visual methods to examine the interactions between the social, spatial, and temporal dimensions of social networks. It seeks to show that visualisations are powerful means for enhancing our understanding of complex relationships that cannot be easily revealed through conventional statistical analysis. Well-generated visualisations can help illuminate the various dimensions and complexities of socio-spatial isolation.

In this paper we present four visual methods for combining and analysing data about people's social networks with their activity patterns. These visualisations utilise both activity-travel data (e.g. activity locations, time spent on various activities, travel time, etc.), and social network information (e.g. social interactions at specific location and time, social network type and social network size). The data used were collected through a specially designed activity-travel diary survey with a sample of Koreans in the Columbus metropolitan area in Ohio (USA). Four company employees and four individuals who are owners of a small shop are purposely selected as a sample to show the effectiveness of the four visual methods. The results show that these visualisations can considerably enhance our understanding of the relationships between people's activities in space-time and their social interactions.

SOCIAL ISOLATION, ACTIVITY PATTERNS AND SOCIAL NETWORKS

Human activity patterns and social networks in space-time – While social isolation may be defined in many ways, it essentially 'denotes a lack in quantity and quality of social contacts' (Delisle 1988). The lack of social contacts may result from a combination of socio-economic, cultural, or physical factors (Delisle 2006). Interpersonal relationships in social networks constitute one of the most important factors influencing social isolation. Limited interactions can adversely affect people's access to various societal resources and result in social isolation. The concept of relationally-based social isolation is directly related to the research tradition in social networks because the focus of social network analysis is on relationships (Wellman 1999). Thus, social network analysis is one method that can be used to examine the occurrence and ramifications of social isolation.

The social networks of an individual often affect his or her access to various resources and opportunities in important ways (Loury 1999). The relationship between a person's social ties and access to various resources is often analysed in terms of strong ties and weak ties (Granovetter 1973). Strong ties are more useful for emotional support and for conserving existing resources (Wellman 1999). Weak ties tend to link peoples across social groups that are made up of close interpersonal relationships. Therefore, weak ties bridge two different groups and provide access to resources that are usually not available within the person's close social group (Granovetter 1973).

Individuals are most strongly influenced by the members of their primary groups – people with whom they engage in frequent interactions (Frank 1996). A person's social network is created through these interactions associated with their routine daily activities. All activities, however, have both specific spatial and temporal characteristics that cannot be separated and are crucial for understanding an individuals' activity pattern (Kwan 2007). People's activity patterns are thus closely associated with the social interactions in their daily lives and important for understanding socio-spatial isolation. As Urry (2003) suggests, physical co-presence is important to keep social relationships alive,

which in turn indicates that people's physical activity space and social networks are closely related. For instance, Harvey and Taylor (2000) found that individuals who are working at home alone want more travelling to overcome social isolation.

Activity patterns or social networks of individuals can reveal problems of social inequality. Yet in previous studies, researchers often focus on either activity patterns or social networks even though they are closely connected. For example, Ohnmacht (2006) criticised social network studies that usually do not consider physical aspects and neglect geographical locations and travel behaviour. Carrasco *et al.* (2007) also argue that even with increasing interest in the topic, little is known about the linkages between social and spatial interaction.

Overall, socio-spatial isolation is complicated and multidimensional because social networks and activity patterns in space and time are closely connected to each other. Some of the processes involved in the pathway from the space-time constraints of people's daily activities and the associated activity patterns to their socio-spatial isolation may be conceived as follows. First, space-time constraints can restrict an individual's activity patterns and spaces (Ettema & Timmermans 1997). Second, restricted activity spaces limit people's exposure to certain places and physical co-presence with other people, both of which are important for keeping social ties alive. Third, limited social interaction further restricts people's activities in space and time, thus aggravating their socio-spatial isolation. This pathway suggests that people's spatial activities both shape and are in turn shaped by their social networks (Fischer *et al.* 1977; Willmott 1986; Rowe & Wolch 1990). People suffer from socio-spatial isolation through both social and spatial disconnection with other people.

From this discussion, it is apparent that three different dimensions should be investigated in order to understand socio-spatial isolation: (1) the temporal dimension, which reflects the timing and duration of an individual's activities; (2) the spatial or locational dimension, which refers to the spatial configurations of the individual's activity pattern; and (3) the social dimension, which can reveal the person's limited social interactions with other individuals.

Space-time activity analysis and socio-spatial isolation – One approach that allows the analysis of the temporal, spatial and social dimensions of social isolation simultaneously is space-time activity analysis based on time geography (Kwan 2000, 2004; Kwan & Lee 2004). In this approach, an individual's existence can be portrayed as a continuous sequence of activities, described as a daily or life path or simply a space-time path (Hägerstrand 1970). It has two main assumptions: (1) a person is indivisible; and (2) without exception, a person always occupies space and time (Parkes & Thrift 1980).

Space-time paths can be used to depict a person's social interactions with other people in the form of repeated coupling or uncoupling with other paths for specific purposes. They can also reveal the structure of social relations in the form of activity bundles associated with various forms of social interactions (Pred 1982). As social isolation may be identified in terms of limited social interactions between a person and other individuals, these interactions are one of the key measures of a person's social isolation. More importantly, a person's limited social network may be the result of various constraints (in a time-geographic sense) on his or her daily activities. Social isolation can thus be illuminated through space-time activity analysis based on time geography (Byrne 1999).

Conceptually, activity bundles of space-time paths, as conceived in time geography, could capture the differences in social interactions between individuals. But, there is no study that uses activity bundles for measuring social interaction because they entail the coupling paths for all members of a social group. This means that huge activity diary datasets need to be collected. Practically, this would be very difficult. Social interaction studies based on activity bundles involve a whole network approach which can show both social and spatial relationships of individuals. Whole network is the view of social networks as aliens might see the Earth's people (Wellman 1999). It assumes that all actors and all their relationships are known. This approach is thus impractical (Carrasco & Miller 2006; Carrasco *et al.* 2007). On the other hand, egocentric networks concentrate on one individual and those who relate to this

individual. Therefore, egocentric networks are "samples" of the entire social network (Carrasco & Miller 2006), and data collection is more feasible.

Many current social network analysts study egocentric networks instead of whole networks for two main reasons (e.g. Wellman 1999). First, it is possible to show one individual's complete network in his/her everyday life while whole networks are usually based on specific and limited spatial boundaries over a limited time because of difficulties in collecting data (e.g. workplace during daytime). The whole network approach may catch only partial networks of an individual. For example, one person who is isolated from his/her working networks in a workplace can manage other networks such as friends or neighbourhood networks. This situation cannot be captured by whole network studies. Second, data availability will be a problem. If one studies a large area such as a county, it will be nearly impossible to get all the social network information of every actor because data collection requires a lot of money and time. Egocentric data collection is therefore more feasible than the whole network approach (Carrasco *et al.* 2007).

DATA

As described in the last section, three different dimensions should be investigated in order to understand socio-spatial isolation: (1) the temporal dimension, which reflects the timing and duration of an individual's activities; (2) the spatial or locational dimension, which refers to the spatial configurations of people's activity patterns; and (3) the social dimension, which can reveal a person's limited social interactions with other individuals. Time geographic methods can help visualise the temporal and spatial dimensions of human activity patterns. But they cannot analyse or visualise social networks. The social network approach can be used to investigate social interactions among individuals. But it is difficult to integrate both the spatial and temporal dimensions of social interactions in the analysis. This study therefore attempts to bridge these two different approaches through undertaking analysis of social networks with the time-geographic perspective. It presents four visual methods that integrate these three dimensions for linking human activity behaviours with socio-spatial isolation. Each method can show different aspects of human activity and social network patterns. It should be noted, however, that these visual methods are qualitative methods for discovering meaningful knowledge from the data. They are useful for exploratory data analysis, which may help inform the quantitative or statistical analyses to be conducted in later stages of a study. However, they have only limited capability for handling a large number of cases without first extracting aggregate patterns using quantitative pattern generation or recognition procedures. But they are still helpful analytical tools as far as they allow us to generate meaningful knowledge using data on a limited number of subjects.

Data for this study were collected by interviewing a sample of Koreans (18 years of age or older), in the Columbus metropolitan area in Ohio (USA). Because of the small size of the Korean population in the study area (around 3,300) and no sampling frame on this population was available, 200 surveys were distributed to Koreans at the ethnic-based businesses in the study area (e.g. ethnic supermarkets, Korean bakeries, and Korean restaurants). This number of surveys gave a reasonably large sample and was feasible in light of the resources available for the study. While 49 surveys were collected, six individuals were excluded from the study either because their activity spaces were well beyond the study area or because they did not provide adequate information about their activities or social networks. The total number of usable surveys for this study is 43.

This paper aims at exploring the usefulness of four time-geographic methods in the visual analysis of social isolation. Eight subjects among the surveyed Koreans were chosen for this purpose. Four of them are self-employed business owners, while the other four are employees working at different companies. The reason for using these two distinct subgroups of the participants is to compare how different space-time constraints faced by their group members affect their socio-spatial isolation. Previous literature has shown that self-employed owners of ethnic businesses often suffer from long work hours and from working alone in small shops where they have only

limited contact with other individuals (Light & Bonacich 1988; Yoon 1997). Because of their stringent space-time constraints, these self-employed "workers" tend to be socially isolated due to their small social networks. Koreans are chosen for this study because their life situations are particularly relevant in this regard: Koreans in the US have a very high rate of self employment (around 20% based on the 2000 census). They often work very long hours and have contact mainly with those family members who work in the same shops (Yoon 1997).

But previous studies have not examined how their long work hours affect their activity patterns, social interactions and socio-spatial isolation. Koreans are therefore a particularly suitable group for investigating socio-spatial isolation. Time-geographic visual analysis comparing the self-employed business owners and company employees in this ethnic group can enhance our understanding of socio-spatial isolation and reveal the usefulness of the four visualisation methods.

Data about the daily activities and social networks of the subjects were collected with an activity-travel diary. The format of the diary was based on Parkes and Thrift's (1980) suggestions, but was more detailed. This instrument has been used in past studies to collect similar data (e.g. Kwan 1998, 1999; Ren and Kwan 2007, 2009; Schwanen & Kwan 2008; Schwanen *et al.* 2008). The data items it collected include: the activity undertaken, the time an activity started and ended, with whom the activity was performed, whether the activity was usually performed at the same time on weekdays, and the location at which the activity was performed. These activity data were collected for three different survey days: (1) one weekday from Monday to Thursday; (2) Friday; and (3) Sunday. One weekday except Friday reflects the normal working day. For many Koreans in the study area, Friday is the day typically used for necessary activities such as shopping, meeting friends, and other non-fixed activity. Sunday may also be important because most people enjoy their flexible time on Sunday.

Only data about the subjects social interactions based on physical contact or face-to-face meetings were collected in this study. Information about people's "cyberspatial" interactions such as those undertaken with telephone, e-mail or Skype was not collected. There are a couple of considerations that led to this focus on people's physical contacts. First, the geographic scope of the social networks engendered by the telephone or Internet may include many locations outside the study area. These locations are arguably less critical in terms of the space-time constraints an individual faces in his or her daily life. Second, some previous studies show that relationships in the physical world tend to be more important than cyberspatial interactions in sustaining people's social networks (Nie 2001; Cummings *et al.* 2002; Ling *et al.* 2003; Urry 2003). The survey instrument and the visualisation methods used in this study, however, can be extended to deal with people's cyberspatial activities (see Kwan & Lee 2004; Ren & Kwan 2007).

Data on the strength of network ties were also collected. Since there are no simple methods for clearly distinguishing strong ties from weak ties, this study collected data on four dimensions of social networks through a questionnaire survey for differentiating these two types of social ties. Each subject was asked to list the names of all individuals he or she contacted (hereafter, contacts) within the previous four weeks. After that, each subject was asked to describe four different dimensions of each contact with a yes-or-no answer: (1) the subject meets the contact at least once a week; (2) the contact provides financial support to the subject; (3) the contact provides emotional support to the subject; and (4) the contact provides reciprocal service to the subject. With data on these four dimensions, a tie is considered weak if none or only one of these dimensions yields a positive answer. For example, if a contact provides only economic support to the subject, the relationship is considered a weak tie. If the contact provides both economic and emotional support to the subject, the relationship is considered a strong tie.

VISUALISATION METHODS

The four visual methods used to analyse the activity and social network data of eight selected subjects are described in this section. These methods are 3D visualisation of space-

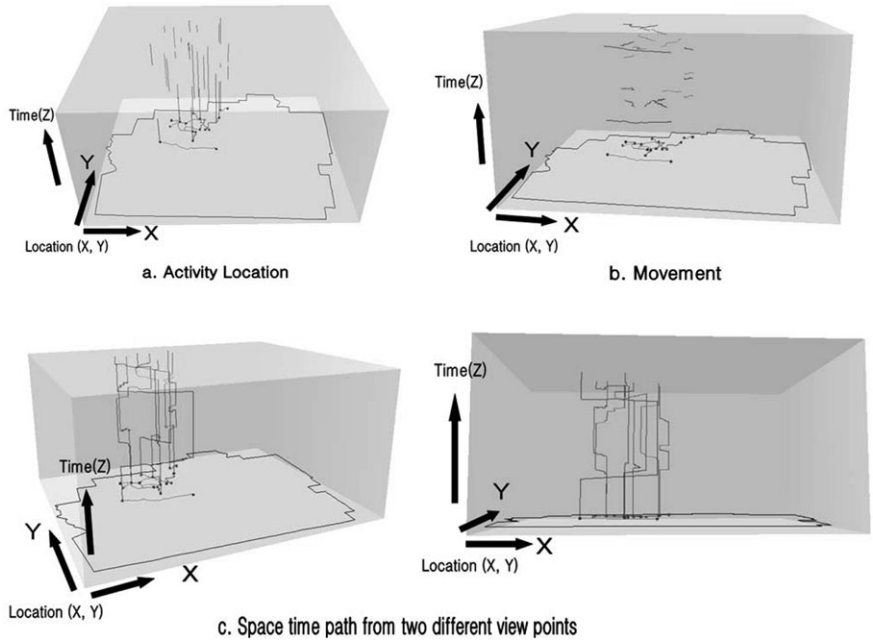


Figure 1. *3D visualisation of space-time paths.*

time paths, time window with social networks, 3D activity density surfaces created with kernel estimation, and ring-based visualisations of social networks.

Space-time paths – The first method used in this study to examine the relationship between people's activity patterns and social networks is the space-time path, which depicts the movement of an individual in space and time in a three-dimensional space based on the time-geographic construct of space-time aquarium (Hägerstrand 1970; Kwan & Lee 2004). In a schematic representation of the aquarium, the vertical axis is the time of day and the boundary of the horizontal plane represents the spatial scope of the study area. Individual space-time paths are portrayed as trajectories in this 3D aquarium (Figure 1). Space-time paths therefore present two types of information: people's activity locations (as vertical segments), and their movement in space and time. Visualising the space-time paths of a group of individuals may help reveal their common constraints and possible interactions in space and time (Kwan 1999).

Time windows – The second method used in this study to examine the relationship between people's activity patterns and social network is the time window. As shown in Figure 2, the outer circle of a time window represents the 24 hours of a day, and the number represents the progress of time in a clockwise manner (1 hour is covered by 15 degrees since a circle has 360 degrees and 360/24 equals 15). The black segments of the outer circle represent the performance of fixed activities, while the performance of flexible activities (whose location or time is not fixed) is represented by the open, colourless segments. The radius of each coloured sector inside the black circle represents the number of contacts. The longer the radius of a sector, the more individuals the person in question has contact with during the time period depicted by the sector. The size of each sector is thus determined by both the number of people in contact (radius) and the time duration (degrees) of the contact. It represents the amount of social interaction over a specific temporal duration.

For example, the time window on the left in Figure 2 shows two different sectors (A-1 &

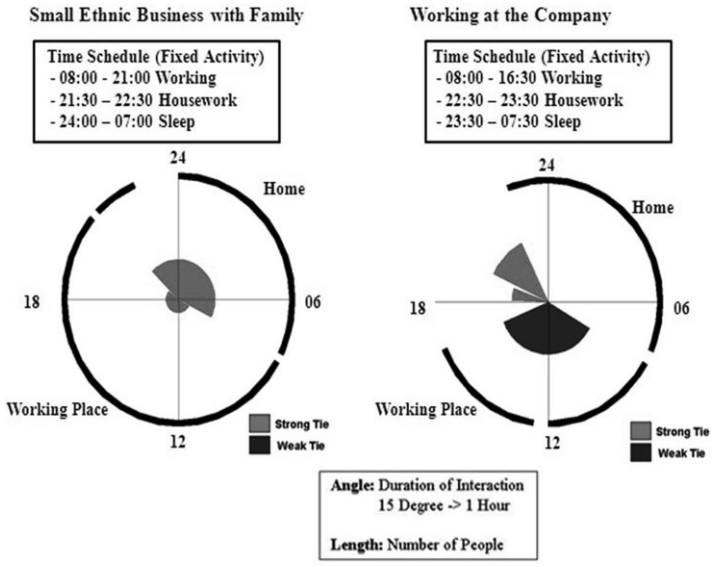


Figure 2. *Time windows with social networks – 2 individuals.*

A-2). The small sector (A-2) represents the amount of social interactions at the workplace. This person works from 8:00 to 21:00 with only one colleague. Therefore, this sector is 195 degrees (15 × 13hours) with a radius of 1. Using the formula ($\pi\gamma 2\theta/360$), the amount of social interactions represented by this section is about 1.70. The larger sector (A-1) in this time window has a longer radius than the smaller sector (A-2). The means the person in question is in contact with more individuals at home after work. The colour of each sector represents the social network type: blue (B-1) represents weak ties, and red (A-1, A-2, A-3) represents strong ties. This time window represents the social interactions of a small shop owner working with her husband. It shows the limited social interactions she has except at her home after work. The time window on the right in Figure 2 represents the social interactions of an employee in another company who works from 8:00 to 16:30. This time window shows his different social networks: several weak ties (colleagues) at the workplace (B-1)* and several strong ties (close friends) with whom he met in an after-work social gathering (A-3)*.

Visualisations using both space-time paths and time windows – While space-time paths and time windows are useful in revealing different aspects of a person's activity patterns or social interactions, they have certain limitations. For instance, it is difficult to visualise a person's social network using space-time paths; while location information of a person's activities or social interactions is absent in time windows. These two visual methods, however, can be linked and used together so that their weaknesses are compensated by the strengths of the other method (Figure 3). This is possible because these two visual methods used the same dataset. Figure 3 demonstrates one individual's space-time path and time window. Based on this integrated use of the two methods, individual's activities over space and social interactions at specific times can be revealed together.

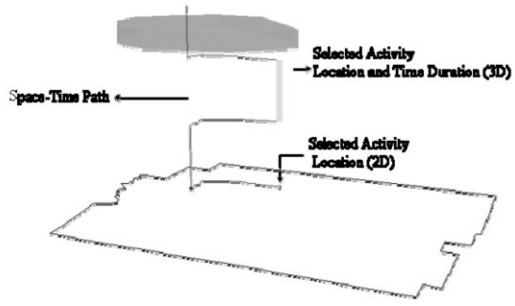
When the space-time paths of individuals are visualised together with their social interactions, important insights can be gained about their social isolation at specific times and places. For instance, during work hours

*Note: Correction added on 18 March 2011 after first publication online on 8 February 2011. '(B-1)' and '(A-3)' were omitted. The errors have been corrected in this version of the article.

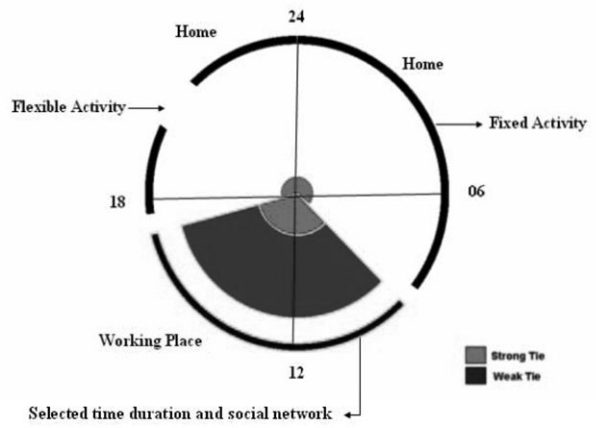
Attributes of Travel_Diary

	OID	PERID	ACTID	DAYNO	ACTNO	ACTDES	PLACE	STIME	ENDTIME	TRAVDUR	ADDRESS	STRONG_TIE	WEAK_TIE
▶	0	1	1	2	0	Home start	Home start	0	8,5		3200 Westbrook Dr,	2	0
	1	1	2	2	1	Work	Work place	9	17	0,5	1975 Morse Rd	5	10
	2	1	4	2	3	Home end	Home end	17,5	24	0,5	3200 Westbrook Dr,	2	0
	3	2	1	2	0	Home start	Home start	0	7,5		4149 Paxton Dr,	0	0
	4	2	2	2	1	Work	Work place	8,1	12,5	0,20	4689 Sinclair Dr, #110	6	8
	5	2	3	2	2	Lunch	Restaurant	13,1	13,9	0,20	800 Bethel Rd	2	0

a. Dataset



b. Space-time path



c. Time window

Figure 3. *Dataset (a), space-time path (b) and time window(c) of one individual.*

and in the workplace, social interactions are mainly with co-workers. So depending on one's workplace, the individuals with whom a person can interact may be very different. The owner of a small shop who works alone, for example, may be able to interact largely with his or her customers during work hours. In contrast, company employees who work in a large company may be able to interact with many co-workers. These interactions with other co-workers can be potential opportunities for expanding his or her social network (not only with co-workers but also with other individuals related to the co-workers). When the location is a person's home, interactions are largely restricted to one's family members or with friends and neighbours in the neighbourhood.

Further, face-to-face interactions, which are essential for maintaining one's social network, require proximity in space and synchronicity in time. But people face many spatial and temporal constraints that limit the possibilities of face-to-face interactions. For example, 11:00 AM is

not a good time to meet for people who need to work at that time at different locations. Although the time and location for a face-to-face meeting may be very flexible for one person, he or she may not be able to meet other people because of the space-time constraints associated with these people's activity schedules. To be able to interact with other people, not only a person's activity schedule but also other peoples' activity schedules are important.

3D activity density surfaces – Space-time paths allow us to visualise socio-spatial isolation of individuals by showing all movements of an individual and those in a similar social group. However, if the number of individuals in the group is large, it may be difficult to discern any patterns due to the large number of paths involved (Kwan & Lee 2004). As a result, different methods have been developed to represent aggregate activity patterns in space and time. One possible method is the activity density surface, which can be created using kernel density estimation and has been applied successfully to represent human activity patterns (e.g. Kwan 2000; Buliung 2001).

Based upon Bailey and Gatrell (1995), activity density surfaces can be derived based on the location and duration of people's activities. The formulation of kernel density estimation follows: if $\Re$ represents the study area, $\boldsymbol{x}$ represents a general location in $\Re$ and $\boldsymbol{x}_1, \boldsymbol{x}_2 \ldots . \boldsymbol{x}_n$ are the locations of the n activities, then the intensity or density, $\lambda(\boldsymbol{x})$, at $\boldsymbol{x}$ is estimated by:

$$\lambda_h(\boldsymbol{x}) = \frac{1}{\delta_h(x)} \sum_{i=1}^{n} \frac{w_i}{h^2} k\left(\frac{(\boldsymbol{x} - \boldsymbol{x}_i)}{h}\right), \quad \boldsymbol{x} \in \Re$$

$$k(\boldsymbol{x}) = \begin{cases} 3\pi^{-1}\left(1 - \boldsymbol{x}^T\boldsymbol{x}\right)^2 & \text{if } \boldsymbol{x}^T\boldsymbol{x} \le 1 \\ 0 & \text{otherwise} \end{cases}$$

where k(.) is the kernel function, the parameter $h > 0$ is the bandwidth determining the amount of smoothing, w_i is a weighing factor, and $\delta_h(\boldsymbol{x})$ is an edge correction factor (Cressie 1993). In this study, the quartic kernel function described in Silverman (1986) is used for generating a kernel surface for each individual in the data set.

In this research, w_i can be calculated from $w_i = t_i(wt_i + st_i)$ where, t_i is time duration of activity at the location, and wt_i and st_i is the number of weak ties and strong ties at the location. Therefore, w_i can be used to represent the amount of social interactions, which is computed as the value of social network size multiplied by the temporal duration of social interactions at a particular location. Based on this formula, the height of the surface over each activity location represents both the amount of time the person spends with other people and the number of people with whom the person interact at that location.

An activity density surface yields two kinds of useful information related to people's activity patterns and social interactions (Figure 4). First, by showing the aggregate activity patterns of the individuals within a particular social group or network, it shows where members of the network or group frequently interact with each other. Further, the estimated density indicates the probability for the group to meet or visit different locations. In contrast to segregation research, an activity density surface can show the spatial patterns of social interactions for a particular social group. The volume covered by the density surface indicates the group's amount of social interaction, taking into account both the duration and number of social interactions at specific locations.

Ring-based social network visualizations – There are different methods for visualising social networks. One example is Appan's ring-based social network visualisation, which uses concentric circles with the innermost circle representing the most recent time slot and outermost ring the oldest time slot (Appan *et al.* 2006). This is an effective way to reveal the temporal dynamics of social networks. This study extends this ring-based visualisation method by adding information about the type of social networks and space-time constraints involved.

Figure 5 shows the result of an aggregate social network of eight different individuals. In this approach, each circle represents a one-hour time duration and there are 24 rings for one day. The innermost circle represents the 0th hour and the outermost ring represents the 24th hour. The number of dots in the 24 rings represents a person's social interactions for one

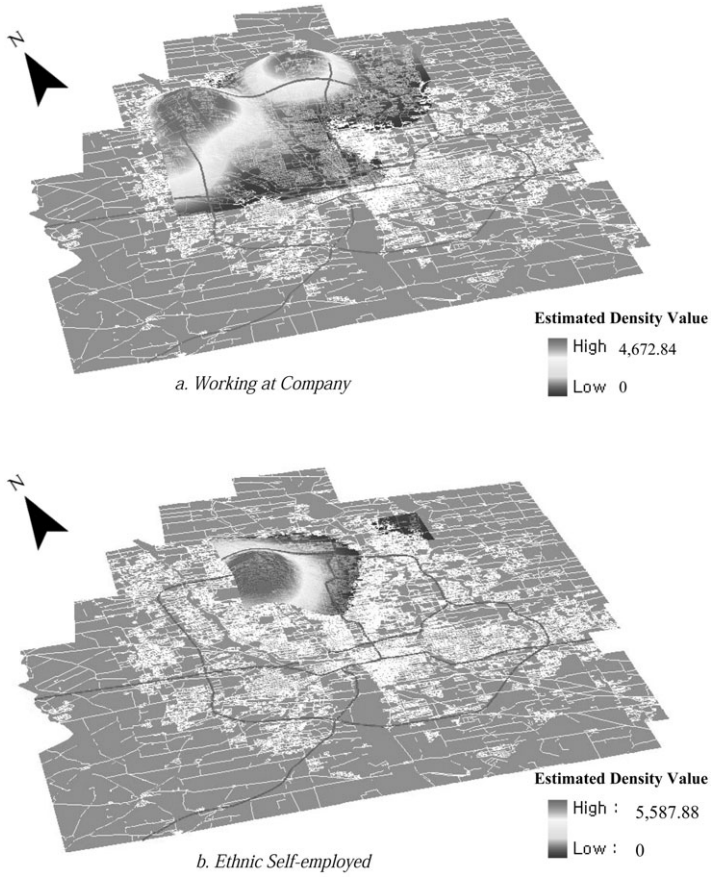


Figure 4. *Activity density surfaces for the two groups of subjects.*

day. One sector of a ring represents one individual. The grey tint means that the interaction was associated with spatial or temporal constraint (e.g. activities fixed in time or location). The white colour means that there was no spatial or temporal constraint associated with that activity (i.e. flexible activity). This visualisation clearly shows the timing and size of social interactions for both fixed and flexible activities. One dot in the circles represents a person with whom each individual (sector) interacts at that time (ring). A red dot (light colour) represents a strong tie, and a blue dot (dark colour) represents a weak tie (See the online version of this article for a colour version of this figure).

Through this visualisation, important insights about the social interaction among the members of a social network can be discerned. First, it shows when and how much flexible time an individual has, and this can be compared with the other individuals in the group. As shown in Figure 5, the four individuals on the left have their flexible hours at more or less the same time during the day, but their flexible hours are considerably different from the four individuals depicted on the right side of the circle. This visualisation also reveals who has the greatest amount of flexible time and how often and how long an individual has flexible time. This comparison can be used to identify individuals and groups who experience "time isolation" (e.g. small amounts of flexible time or flexible time that does not coincide with that of other members in the social network). Second, each individual's social network type and size can be shown through this kind of visualisation. In Figure 5, the four individuals

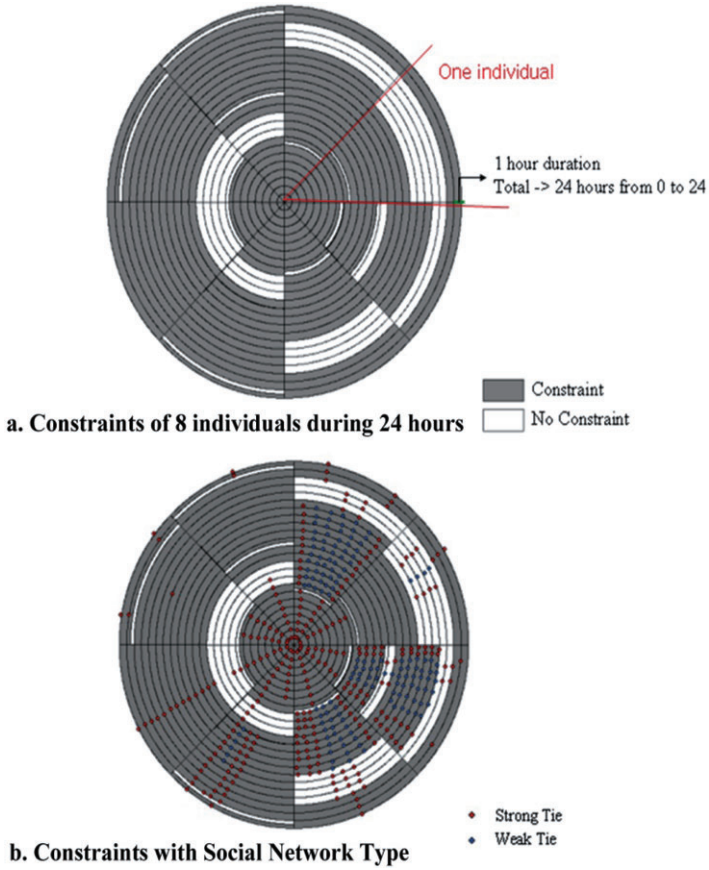


Figure 5. *Constraints of 8 individuals during 24 hours.*

on the left have a smaller social network than the four individuals on the right. Third, each ring represents a different time. Therefore, the social interactions of a group at specific times can be examined. Although ring-based visualisations do not provide location information, they are particularly useful for comparing the social interactions of two different groups at specific times or for examining the social interactions of one group at specific times.

ILLUSTRATIVE APPLICATIONS

Using the four visual methods described above, the activity patterns and social interactions of eight selected subjects were explored to illuminate their socio-spatial isolation. Four of them are self-employed business owners, while the other four are employees working at different companies. Figure 6 shows the space-time paths and time windows of the two groups of individuals on three different days. The top left pane shows four space-time aquariums with weekday space-time paths of the eight individuals. The top two aquariums represent the paths for the self-employed group while the bottom two aquariums represent the company employee group. Two different views of the space-time paths are presented. The first view (on the left) emphasises the location of activities, and the other view (on the right) highlights the duration of the time spent on those activities. Using the interactive 3D geovisualisation capabilities of a geographical information system (GIS) (e.g. zooming, panning and rotating), it can be observed that the space-time

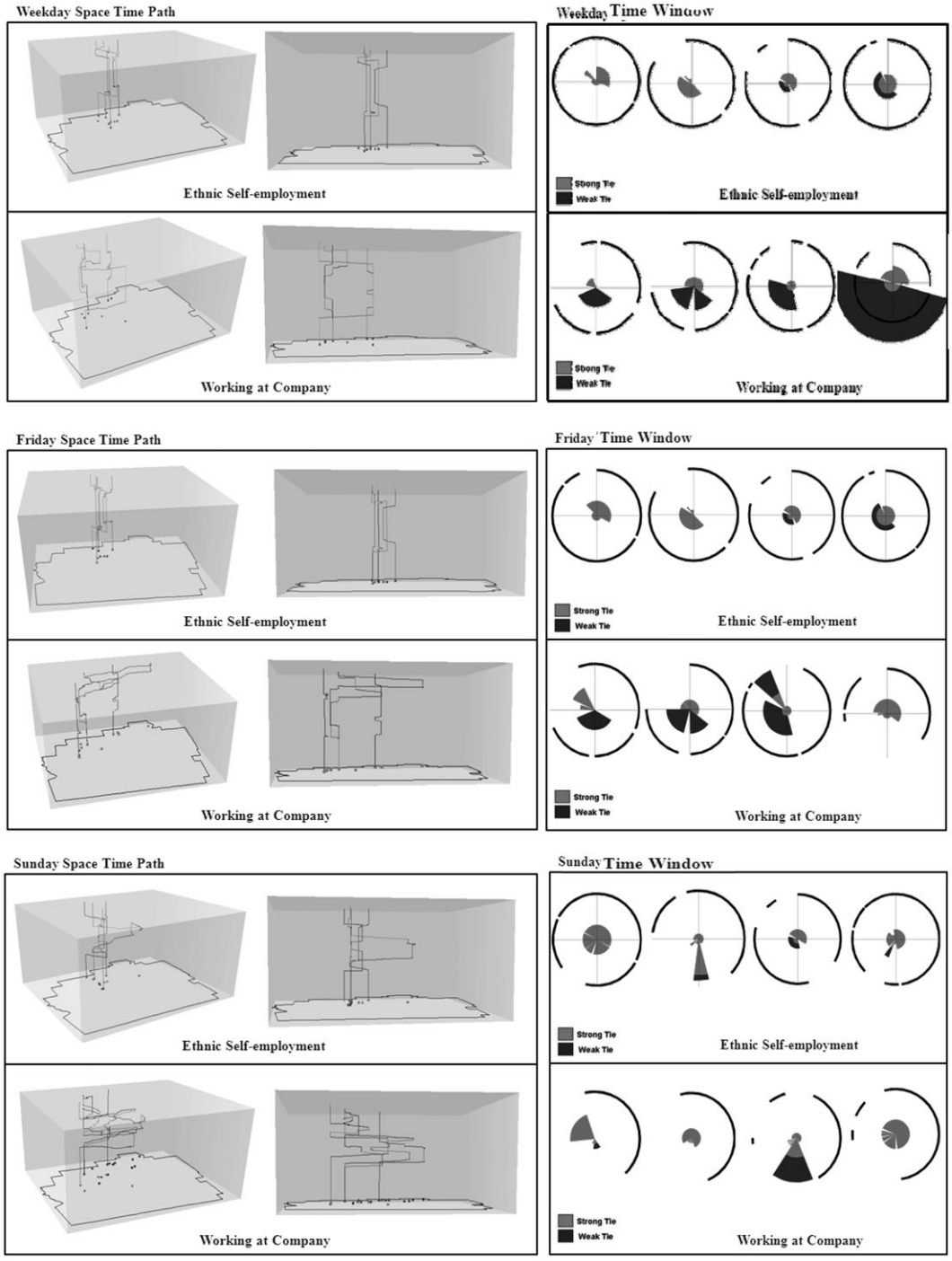


Figure 6. *Space-time paths and time windows of the eight selected subjects.*

paths of the self-employed individuals are more spatially restricted than those of the company employees. Individuals in the self-employed group have longer working hours, more restricted activity spaces, and fewer weak ties than the company employees.

Long working hours can be seen from the vertical segment of the space-time path of each individual (Figure 6). The space-time paths of the four self-employment business owners tend to have three long vertical segments – the middle one represents their work hours during the day – while the space-time paths of the four company workers are characterised by several short or long vertical segments. The spatial scope of the activity spaces is indicated by the short non-vertical segments between the vertical segments. For individuals in the self-employed group, the short non-vertical segments indicate short trips from home to workplace. Long commutes are not possible because of the long working hours of the self-employed business owners. As a result, ethnic business workplaces are often located near the residential areas where their owners and most of their customers live. Further, individuals in the self-employed group visit fewer locations than the company employees, especially on Sunday. The time constraints of self-employed business owners therefore restrict their spatial movements and activity spaces.

On the right of Figure 6 are the time windows of the eight selected individuals. These time windows reveal considerable differences in the social interactions between the two groups. Individuals in the self-employed group have more limited social interactions than the company employee group, as indicated by the smaller inner circles of the former group (especially with regard to the number of weak ties). The self-employed group also has less flexible time (open, colourless segments of the outer circle), because their working hours are usually very long. Three of the self-employed business owners even open their shops on Sundays (as revealed by the dark outer circle with little colourless openings). These differences have important implications for the amount of social interactions possible and the size of the social network for the two groups.

Visualisations using both space-time paths and time windows simultaneously can reveal the spatial and temporal characteristics of a person's social interactions. This approach can provide detailed information on an individual's access to physical and social opportunities. Through showing the location and timing of activities and the kind of social interactions they entail, this integrated approach effectively links both the spatial and social dimensions together and is capable of shedding significant insights regarding each individual's potential social and spatial opportunities.

Figure 4 shows the activity density surfaces for the selected individuals with the two different job types. Figure 4a shows the surface for the four company employees while Figure 4b shows the surface for the four self-employed business owners. Both density surfaces were created using data on their activities for the three survey days; namely, one weekday, one Friday, and one Sunday. As shown in Figure 4, the activities of the company employees cover a wider geographic area and less concentrated at the peaks, while the density surface for the self-employed groups is more spatially restricted and with a more concentrated peak. Although these visualisations provide less information when compared with the subject's space-time paths, they nevertheless corroborate the restricted activity spaces for individuals in the self-employed group and their limited possibilities for social interactions.

Figure 7 shows the ring-based visualisations of social networks for the eight individuals during the three survey days. The four top sectors represent the company employees while the four bottom sectors represent the self-employed group. On weekdays and Fridays (Figures 7a and 7b), the differences in social networks can be seen clearly. During work hours, the self-employed business owners have much fewer weak ties than the company employees, who tend to have more contact with co-workers (weak ties). The self-employed subjects usually work alone or with their family members (strong ties). Subjects working at a company also have more flexible time, especially in the evening; while the self-employed business owners tend to work longer hours and have limited flexible time throughout the day. This difference in the amount of flexible time can be seen more clearly in the results for Sunday (Figure 7c). Three indivi-

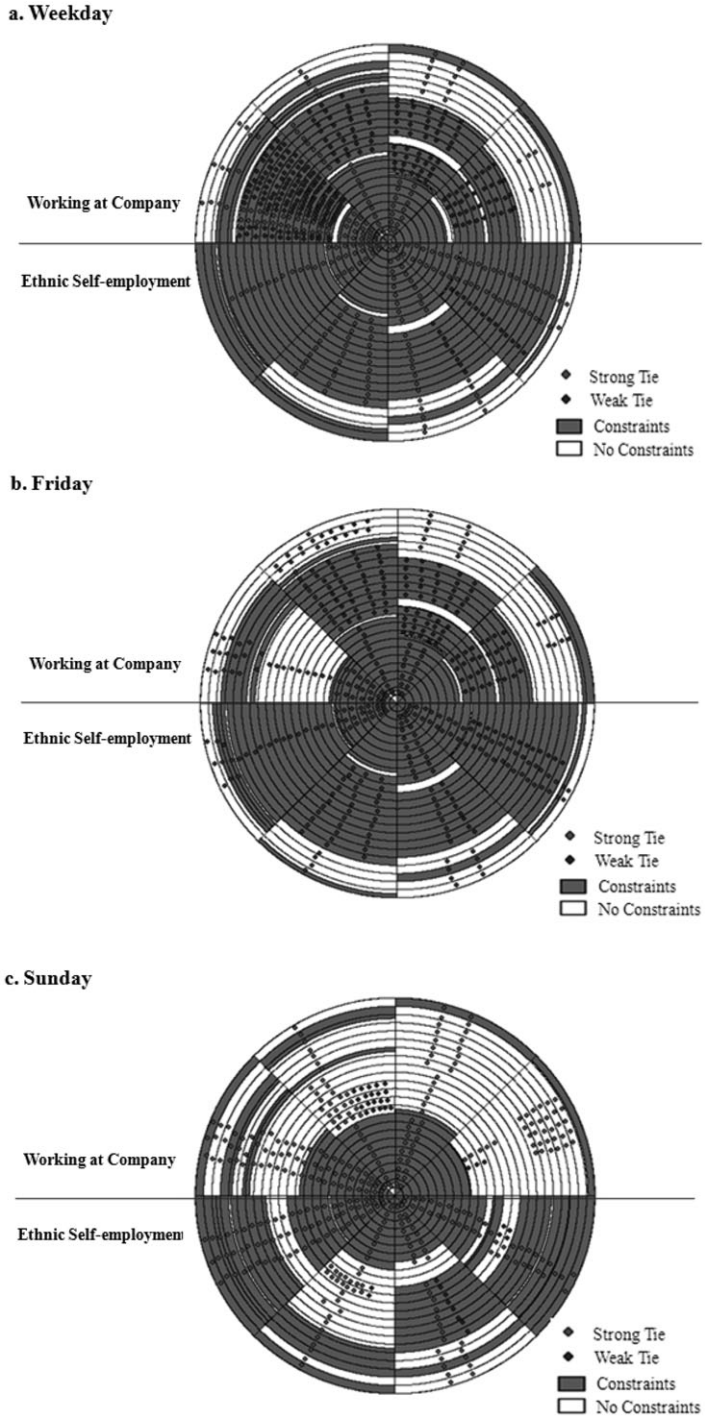


Figure 7. *Ring-based visualisations of social networks of the eight individuals.*

duals of the self-employed group work on Sundays, and this means that they have less flexible time to interact with others even on Sundays. With these ring-based visualisations, socio-spatial isolation can be identified in terms of the limited social interactions resulted from a lack of flexible time and few weak social ties at one's workplace. These are the main reasons for the social isolation of the self-employee business owners surveyed in this study.

DISCUSSION AND CONCLUSION

Few previous studies of socio-spatial isolation have explored both its spatial and temporal dimensions. This study shows that various visualisation methods that focus on these dimensions can considerably enhance our understanding of socio-spatial isolation. As shown in the study, space-time paths can reveal: (1) the temporal isolation of an individual (e.g. long work hours restrict travel and limit the time available for social interactions); and (2) the spatial isolation of an individual (e.g. limited activity spaces and limited access to physical or social opportunities). Time windows allow us to visualise temporal isolation (e.g. limited possibilities to meet new people), and social isolation (e.g. limited size and type of social interactions). Activity density surfaces reveal the aggregate spatial and social patterns of the activities of different groups. They enable us to assess which groups have limited access to physical and social opportunities. Lastly, ring-based visualisations of social networks show the amount of time available for social interactions, and the type of social ties involved in the activities at different times of a day. Each of these approaches is therefore capable of revealing different aspects of socio-spatial isolation. Since human social interactions often involve both physical and social aspects, analysing both of these aspects with a focus on the spatial and temporal dimensions simultaneously would greatly enhance our understanding of human activity and social network patterns for each individual.

This study contributes to advancing our understanding of socio-spatial isolation in several ways. First, it implemented visual methods that are capable of showing the multidimensional aspects and material basis of socio-spatial isolation. Socio-spatial isolation is complicated and multidimensional because people's social networks and activity patterns in space and time are closely connected to each other. One way to understand these various aspects is to examine the spatial and temporal characteristics of people's social interactions (via their daily activities), in their everyday life (Schnell & Yoav 2001). The visual methods used in this study reveal the social interactions in people's everyday life spaces, which cannot be easily revealed through other means. Although previous studies have argued that social, spatial or temporal aspects of social isolation are connected to each other (Fischer *et al.* 1977; Willmott 1986; Byrne 1999; Rowe & Wolch 1990; Ohnmacht 2006; Carrasco *et al.* 2007), few if any of them have explored methods that can connect these aspects together.

Second, this study presented unique and efficient visual means for understanding the space-time complexities of socio-spatial isolation. They overcome several limitations of conventional analytical methods. For instance, few conventional methods were designed to handle real geographic locations of human activities and interactions in a study area (Kwan 2000). Often, the spatial dimension is represented by some measures derived from real geographic locations (e.g. distance or direction from a reference point such as home or workplace). Further, locational information of activities and trips was often aggregated with respect to a zonal division of the study area (e.g. traffic analysis zones). The visual methods used in this study, however, deals with real geographic location. They are capable of showing a lot of information about people's activities, social interactions, their geographic location, and their timing and duration with only one map or graph. They can be used to explore the complex relationships between people's social and spatial interactions, which may not be readily revealed by conventional methods.

Third, the visual methods can also be applied to understand socio-spatial isolation for other social groups, such as the disabled, the elderly, homeless people, single parents, and women. Since different social groups may experience socio-spatial isolation for different reasons, the

methods can help highlight the impact of the space-time constraints experienced under different life situations. For instance, women with young children tend to face rather restrictive space-time constraints associated with their household responsibilities (Tivers 1985; Kwan 1999). They may have limited time for undertaking out-of-home activities, meeting their friends, or connecting with other individuals due to their gender role. Physically handicapped or elderly people, on the other hand, may be highly dependent on their friends or family members to help them get outside of their homes. Since help will be less likely during daytime when these members of their social networks need to work, they may experience socio-spatial isolation (especially during the day), due to the lack of timely assistance. The spatial, temporal, and social aspects of a person's activity pattern thus heavily shape his or her experience of socio-spatial isolation. The visual methods presented in this paper can help explore and highlight the importance of these spatial, temporal and social dimensions, as well as the underlying processes that lead to people's social isolation from certain physical or social opportunities.

Each of the four visual methods, however, has its specific limitations. For instance, it may be difficult to identify patterns from the space-time paths of a large number of participants (Kwan 2000). A time window depicts the relationship between activity pattern and social network for only one individual. Information presented in ring-based social network visualisations may not be legible with more than 12 individuals. It should be noted, however, that visualisations are qualitative methods for discovering meaningful knowledge from the data. They are useful for exploratory data analysis, which may help inform the quantitative or statistical analyses to be conducted in later stages of a study. The capability for handling a large number of cases is not essential (which is one of the strengths of quantitative methods), if they allow us to generate meaningful knowledge using data on a limited number of subjects. Further, some of these limitations may be ameliorated to a certain extent using additional techniques. For instance, it is possible to identify patterns from a large number of space-time paths after certain standardising transformations or using group-based analysis with the help of an interactive geovisualisation environment (Kwan 1999, 2000). Representative patterns may also be derived using computationally intensive pattern generation methods such as sequence alignment (e.g. Shoval & Isaacson 2007).

In addition, the need for detailed individual-level data and software tools to implement these visualisations is also a major limitation in using the visual methods. While current geographic information systems (GIS) can create 3D activity density surfaces, there are no readily available procedures for generating space-time paths, time windows or ring-based visualisation of social networks in current GIS or other software. Dedicated computer codes are required to create the visualisations presented in this paper. Programming skills are therefore necessary to implement three of the visual methods.

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