Final Report of ITS Center Project: Regional pedestrian activity measurement

A Research Project Report

For the ITS Implementation Research

A US DOT University Transportation Center

REGIONAL PEDESTRIAN ACTIVITY MEASUREMENT (PROJECT 434911)

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Words of Appreciation

This effort greatly appreciates the resources and time the following individuals and organizations provided.

The U.S. Department of Transportation, University Transportation Centers Program, and the Virginia Tech Transportation Institute – for their fiscal and resource support.

Nextel, specifically Helen Franks and Marselle Culpepper for their willingness to loan us two phones, associated service, and applications.

Kathy Hosig, Ph.D. and Lisa Schweitzer, Ph.D. for their invaluable expertise.

Project overview

American society has become automobile-centric to such an extent that any inquiry into alternative modes of transportation – those modes that are not dominant – frequently finds little response as little data or information exists for such modes. The ever-increasing general awareness of the systemic nature of resources that began in the 1990s spawned an extensive set of inquiries that attempted to reach into the environmental and health benefits of alternative modes of transport. Lacking data on alternative modes, practical inquirers set out to determine if existing automobile data collection mechanisms could be used for alternative mode data collection. For example, transportation professionals sought additional utilization of existing traffic cameras, capable of counting and classifying automobiles, to also count pedestrians. Though this approach seems practical, the assumption that pedestrians follow the same rules and roads as the automobile is questionable.

To better understand pedestrian behavior, oral and written surveys and travel diaries have often been used. But these can lack accurate spatial characteristics of movement, as the participant may not convey all information. Technical data collection has improved this. Wearable technologies that collect the pedestrian's spatial location and prompt them to provide a response as to why they have just changed direction, etc. have been used. While collecting a tremendous amount of information on a pedestrian's location, and their decision-making, they can impede the pedestrian's progress, as they will interrupt the pedestrian's routine with inquiry. However, a large-scale deployment of such wearable tracking technologies – to collect the whereabouts of a population of participants – combined with land use and other data sets to provide a comparative commentary on participants' movement – may reduce the challenges of a survey of individuals while providing a significant amount of information to inquirers as to human movement in a region. Further, given the nature of funding for organizations interested, and given the technological capabilities of today's wearable devices, it may be of great interest to team between several disciplines, provide one wearable technology architecture, and glean data relevant to multiple disciplines' inquiries.

It was the impetus of this effort to provide a review of those who would be interested in such a study, and take a quick look at wearable technologies and their associated wearable architecture arrangements in order to establish the basis for deploying something of this nature. This effort revealed that those disciplines interested in human movement through a region are quite diverse, ranging from public safety to biomotion. However, teaming for an immediate co-beneficial technology deployment would be those involved in the health and well-being of a person (for example, physical activity) and those involved in transportation (for example, transportation planning and engineering).

In terms of wearable technologies this effort developed and evaluated six wearable architectures and found that at least two, with some modification, would be worth further exploration. The critical features in their use between the researchers and the participant (the wearer) are cost, the number of devices to carry, and the number of steps involved in device maintenance. Minimizing all is critical to the success of a future deployment.

This project's initial objectives and tasks follow.

Project objectives

The goal of this project was to develop a detailed understanding of what would be required to undertake a wearable-technology pedestrian survey and to establish, as a foundation, the next step of technology prototyping. Over the long term, the goal would be to develop and deploy a wearable-technology pedestrian survey using wireless technologies, Global Positioning System (GPS) receivers, and clothing-integrated accelerometers. Such a deployment would benefit researchers in multiple domains including: human health and medicine, civic planning, and transportation.

Project tasks

The tasks as initially drawn out for this effort include those listed below. Many of the tasks were conducted simultaneously.

- Review literature on pedestrian movement: Macro (region-wide) - automated tracking, surveys, or systems similar to the one described above; Micro (human physiology) relative to transportation systems and facility design - how may accelerometer systems help to improve design under 'real-world' survey?

- Review technologies: Macro (reviewing portable GPS technologies); Micro (reviewing human-movement assessment technologies such as wearable accelerometers).

- Assess the feasibility of integrating technologies while considering the pedestrian survey participant: technology integration (wireless connectivity vs. data storage); human-technology integration; and cost.

- Identify key stakeholders who are interested in this area of research and begin to establish collaborative relationships.

- Conduct real or virtual 'round-table' sessions with domain experts to determine overall feasibility and validity - "if such a survey were possible, in what might you be interested?"

- Develop prototype technology concept and survey deployment schemes.

- Develop final report synthesizing above findings.

Project accomplishments and findings

Review of the literature

The initial phase of this effort began with an examination of the international and national interest in the study of human motion. This snapshot provided insight into cross-discipline interest and nomenclature. The review culminated in late October of 2005 with a presentation to Association of Collegiate Schools of Planning (ACSP) conference in Kansas City. The presentation of the paper, "Pedestrian Activity Measurement: A Review of the State of the Art and the State of the Practice," was given in a new session at the conference, Built Environment and Physical Activity. The new track serves as a nexus of health and urban planning academics and practitioners. It quickly became standing room only – clearly demonstrating that the communities of health and urban planning are ready to commit to formally discussing, and addressing, the issues with land use and physical wellness. With urban planning's close association to transportation engineering, it seems likely that a health, planning, and engineering dialogue will commence on the same topic.

The initial findings presented were the highlights of a review encompassing the many disciplines that have an interest in pedestrian activity measurement. Dominant were the urban planners and transportation engineers. These disciplines collect data on pedestrian movement through a region or at the streetscape (for example, a count of pedestrians crossing at an intersection). Disciplines interested in the physical wellness of the pedestrian also had representatives who were also very interested in the effort. Such wellness of the pedestrian includes: the physical security of the individual, for example, walking at night with or without street lighting in an area known to have a high crime rate; the safety of the individual walker, for example, the ability of the pedestrian to evacuate a building or a region; and the health of the walker proper (e.g., the motion of the body through space across varying terrain [biomotion studies]).

The full details of this research may be reviewed in Appendix C, where "Pedestrian Activity Measurement: A Review of the State of the Art and the State of the Practice" is presented.

Identification and communication with people and disciplines of interest

Review of the literature still left a series of practical questions unanswered: If a study were to be conducted locally and regionally, who might be interested in the movement of people? Who might be experts in conducting practical experiments involving people in general? Who might be in need of data or information on the movement of people in general? In answering these questions for this effort, an attempt was made to communicate with local, regional, and statewide actors that might have interest in seeing a project evolve to capture data on pedestrian and regional human movement in general. This search began in the organizations encompassing the Virginia Tech Transportation Institute (VTTI). This included a search of Virginia Tech, Blacksburg (the town in which Virginia Tech resides), and the state of Virginia. It is unusual for a region to have access to the technological sophistication that Virginia Tech offered. In this regard, our effort had a significant advantage over regions that do not maintain such a University. However, the other institutions, the inter- and intra-regional actors involved in health, planning, transportation, safety, pedestrian and bicycle activism, etc. are not necessarily unique to this region. As such, any follow-on research or deployment would be able to identify similar actors in their regions that may wish to partner, or assist, with the research or deployment of such tracking technologies.

Organizations that may prove of universal interest to such an activity include:

- Regional pedestrian, hiking groups, or bicycling
- Planning offices
- Safety offices
- Engineering offices
- Transportation offices
- Health and nutrition organizations

A complete list of communications may be reviewed in Appendix A.

Development of initial concepts

Prior research experience in wearable technologies, a review of associated literature, and communications with international, national, and local experts led to the development of several conceptual systems for capturing and analyzing data on pedestrian location. These systems included a field and desktop technological component. The desktop component was similar across all conceptual varieties. The desktop technology included a computer connected to the internet capable of connecting to the field devices either directly or through the internet: this desktop system was the central repository for collected data and could serve also as a data analysis and sharing mechanism.

The field technology component for any of the concepts was to be a collection of wearable technologies that afforded information about the wearer’s location and movement. These devices were to provide this information with minimal impact on the wearer. That is, one would affix them to their person, activate the technologies, and go about their daily routine. At no point should the wearer need to reactivate or respond, or otherwise interact with these devices till the end of their daily routine when they would likely need to perform some kind of daily maintenance ritual with these devices, such as downloading data or charging the batteries. The hope being that while worn, the individual wearer would forget that he or she was participating in a study, thereby reducing user bias.

In should be noted that there were two papers that proved critical in the development of these concepts. The papers provided documented examples of real-world data collection and rapid analysis techniques.

Any further investigation into deployment of such technologies should involve a review of papers and their associated research.

Oliveira, et al., used two data-logging field technologies, an Actigraph accelerometer and a Geostats Wearable Geologger GPS receiver, to capture the location and movement of an individual.[1] Following data capture, a proprietary data analysis system, GeoStats Trip Identification and Analysis System (TIAS) was used to determine the individual's activity and assign a probability of transportation mode of the wearer's daily activity. The technological application of this research proved uniquely compelling to the development of the wearable concepts for this effort. In their research, an individual wearing such technologies was capturing travel origin and destination information, and the technologies that were assigned to collect movement information, number of steps taken or level of activity, was also being used to associate with the location information to provide modal information. In one instance, multiple disciplines' inquiries into the condition of a pedestrian were capable of being addressed.

Doherty et al. used a Bluetooth-enabled cell phone in combination with a Bluetooth-enabled GPS receiver to collect information on an individual's location in near-real-time.[2] A GPS signal collected by the GPS device was sent to the cell phone via Bluetooth, and the cell phone, with appropriate service, then sent that information on and through the internet to the researcher's central repository for analysis. Additionally, their design used the unique capabilities of the cell phone to allow the wearer to respond to a location-based prompted recall survey. It was their intention to find out more about travel habits through such prompted recall. While their technological sophistication was one that this effort sought to emulate, the two efforts differed philosophically on the prompted recall. In theirs, they actively captured additional information from the wearer when that individual approached a specific location. In our effort's concept, it was believed that such prompted recall might interfere with an individual's decision-making processes on choice of path or mode, thus, the movement alone, in combination of other data sources, would provide data for later analysis.

Further communications with Doherty revealed additional capabilities that had been developed.[3] His team had established a sever which would accept Geospatial Information System (GIS) files of a region's roadway network and land use as well as any GPS tracks collected by an individual wearing technology as described above. This information would then automatically generate a probability of the individual's transport mode. Thus, the simple technology that provides a location for the individual, when compared with additional information, can provide insight into that individual's movement to address multiple disciplines' inquiries.

The analytical capabilities the aforementioned research efforts were well documented and sound. They demonstrated that there were stable and accessible applications for data analysis that could accept inputs from a wide variety of standardized technologies to provide insight into pedestrian movement. This suggested that our initial objectives could be more focused; our effort could focus on how to capture and store the data rather than how to analyze the data. Thus, our efforts focused in on determining how friendly wearable devices were in terms of cost, comfort, configuration, and data collection.

The VTTI research effort's initial conceptual architectures included:

- Wearable Concept 1 – disparate data loggers. In this architecture there is a wearable accelerometer that is capable of storing some quantity of activity data (at least a day's worth at 1-second intervals). There is also a wearable GPS device capable of storing some quantity of activity data. In such a case, some maintenance of the devices is required. Data would need to be

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[1] Oliveira, M., P.J. Troped, J. Wolf, C.E. Matthews, E.K. Cromley, and S.J. Melly. 2006. Mode and Activity Identification Using GPS and Accelerometer Data. 85th Annual Transportation Research Board Meeting, Washington, DC

[2] Doherty, S.T., D. Papinski, M. Lee-Gosselin. 2006. An Internet-based Prompted Recall Diary with Automated GPS Activity-trip Detection: System Design. 85th Annual Transportation Research Board Meeting, Washington DC

[3] E-mail and phone communications with Sean Doherty in Spring and Summer, 2006.

downloaded and the device's power supply replenished. This concept is similar to that defined by Oliveira, et al.[4]

- Wearable Concept 2 – a data storage device wired to two collectors. In this instance, an accelerometer is attached to a wearable storage device that is simultaneously connected to a GPS unit. Thus, the participant carries three devices, wired together. The computational device could include a laptop or a handheld computer, which collected and stored the data for later download. Maintenance for this would require downloading data but from one device, and replenishing the power, but this time, for three devices.

- Wearable Concept 3 – data storage device wirelessly connected to two collectors. This concept is identical to Concept 2 but the storage device is connected via wireless short-range communications, such as Bluetooth, to the peripheral accelerometer and GPS device. Again, like Concept 2, this device would have a download requirement from one device and a power-replenishing requirement for three devices.

- Wearable Concept 4 – data conveyor wirelessly connected to two collectors. This concept is similar to Concept 3 in that there are no wires connecting to any of the local (wearable) devices, but the storage device is swapped out for a device which first collects the local data and then conveys the data elsewhere, presumably, to a server maintained by the researchers. In this concept, the GPS and accelerometer peripherals are wirelessly connected to a cell phone that transmits its information through the internet to a server for storage. Here too, three devices would require power replenishment. However, data download is conducted automatically. Minus the accelerometer, this concept is similar to that defined by Doherty, et al.[5]

- Wearable Concept 5 – data conveyor wirelessly connected to two collectors. This concept is identical to Concept 4 but a WiFi-enabled handheld computer replaces the cell phone. Data is collected from the peripheral devices and logged until the central device locates a 'friendly' WiFi service, automatically connects, and sends its information to a server. Like Concept 4, power replenishment is the only frequent maintenance requirement, unless a friendly network cannot be located in some amount of time.

- Wearable Concept 6 – integrated conveyor and one collector. Here, the peripheral GPS device is replaced by a cell phone (conveyor) with integrated GPS chip and wirelessly connected to an accelerometer. In this instance, there is no data maintenance required; there is only power replenishment for two devices.

- Desktop Concept – data collection and sharing for analysis – The original concept for the database design was to create an integrated system that is easy to upload information into and display the results. The components to this system included: a high-speed internet connection; a dedicated IP address; a web server; a database; an automated mechanism to upload data from field devices to the database; an automated mechanism to graphically display location information; and a connection to the internet to share collected data.

Refining concepts and evaluating technologies

Reinterpreting concepts into reality, even such as those so well documented in the papers described above, are often challenged by reality. Our effort contended with the following requirements: test several technological aspects of several concepts (size, weight, ability to provide useful data); a 5000-dollar technology budget; human resource restrictions that would allow our study to mimic that which would be available to a likely future champion of such a study: local governments and city planners. The considerations for technology selection in our effort follow.

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4 Oliveira, et al. 2006.

5 Doherty, et al. 2006.

Wearable Concept 1 called for a wearable data-logging accelerometer and GPS device. The GPS device used by Oliveira, et al., was no longer available at the time of this effort.[6] Further, the GPS device they had used required the use of a backpack. Though much less substantial than those used 5 years prior to the writing of their paper, their GPS device had a small antenna placed on the shoulder pad of the backpack of the participant and the primary electronics in a small pouch that would reside within the backpack. Compared to the scale of the accelerometer they were using, this seemed quite large. The GPS device they had used conflicted with our effort's focus on assuring minimal technological interference with the individual wearer's daily routine. Thus, a low-cost, lightweight, and compact GPS data logger was sought out. Though GPS accuracy, data-storage capacity, and battery life likely would suffer as compared with the GeoStats device, our effort chose the Trackstick for its simple design and small size to serve as GPS data logger in Wearable Concept 1.

As for the data-logging accelerometer identified in Wearable Concept 1, the GT1M ActiGraph accelerometer used by Oliveira, et al., was still available and affordable and so was acquired for our effort.[7]

Wearable Concept 2 called for a mouse-like accelerometer and mouse-like GPS to be simultaneously attached to another device that could be used to store the collected data. This design quickly proved infeasible. First, two devices connected to another with wires would become quite a hindrance to any wearer of the technology. Second, most mobile systems capable of hosting two wired Universal Serial Bus (USB) connections (the preferred wired connector for small, mouse-like, devices) are laptops, so the weight and the cost would quickly skyrocket. Wearable Concept 2 was no longer considered.

Wearable Concept 3 called for two small, nearly unobtrusive devices, connected wirelessly to a third small device that collects data and stores it for later download. Concept 3's basic wearable wireless trio design is consistent through Concepts 4 and 5 where two data providers are sending data to a third data handler. As such, technological acquisition could focus on a few technologies that could double or triple time across the evaluation of each concept. Wearable Concepts 3, 4, and 5 all seek a Bluetooth (local wireless) enabled GPS device. This device would need to be fairly small, durable, reliable, accurate, and easy to maintain (simple and infrequent charging). After exhaustive research as to the accuracy of the newest available retail GPS chips, three GPS devices were selected.[8] Three different providers were selected because as while the chips remained the same, the batteries, charging technique, provided software, and the housing all varied somewhat. These were the Globalsat BT338; Sysonchip Smart Blue Mini; and Holux GPSlim236.

Wearable Concepts 3, 4, 5, and 6 all seek a Bluetooth-enabled accelerometer. At the time of the technology selection and acquisition phase of this effort, there were very few options for this component. Through conversation with Mr. Doherty,[9] a Bluetooth-enabled accelerometer was identified as being in production and sale through the Australian firm, Alivetec.[10] Indeed, this firm's product offering included a Bluetooth-enabled accelerometer coupled with a heart monitor that communicated its information to a Bluetooth-enabled cell phone and on to a centralized monitoring service. This concept is very much akin to those presented here. However, being coupled, the device had a cost of around $1000, which was prohibitive in this effort.[11] At the time, the only other alternative was to assemble a device based on the schematics outlined by a Georgia Tech engineer.[12] While plausibly inexpensive in terms of materials, is also seemed plausible that it could become quite expensive in the time involved to identify a VTTI engineer capable of assembling the device, the time to build the device, the time to calibrate and test the device in a

6 Oliveira, et al. 2006.

7 Oliveira, et al. 2006.

8 E-mail and phone communications with Sean Doherty in Spring and Summer, 2006.

9 E-mail and phone communications with Sean Doherty in Spring and Summer, 2006.

10 http://www.alivetec.com/

11 E-mail and phone communications with Sean Doherty in Spring and Summer, 2006.

12 http://www.gvu.gatech.edu/ccg/resources/btacc/index.html

way that is behaved in a fashion similar to the device used by Oliveira, et al, etc.[13] Thus, it was decided that the Bluetooth accelerometer in the wearable concepts would be temporarily set aside and our effort would use the ActiGraph device to serve as a fill-in as its data captured and size would likely mimic a real Bluetooth accelerometer. Not surprisingly, by the time of the writing of this report, there are more Bluetooth accelerometers available on the retail markets. However, they are generally tied in to complete, individual, health-monitoring packages, and as such, remain relatively pricey, and their analytical software has been developed for a very specific use.

Wearable Concepts 3 and 5 both call for their third device to be capable of storing the data for later transmission. Where Concept 3 assumes that the data transmission will be through a physical connection, Concept 5 augments that with a capability of transmitting the data via a 'friendly' WiFi connection. That is, when the storing device enters the range of a previously identified wireless network, and it determines that there is an internet connection through that friendly network, it then sends the collected data. There are a lot of similarities between the two devices. Concepts 3 and 5 both must have a Bluetooth capability and must be able to store data. At the time of the selection process for this effort, there were several capable technologies that were small enough and relatively inexpensive enough to perform these basic functions, not to mention capable of being programmed and connecting to a WiFi service. Since a device with WiFi can also store data, two devices were required to serve as a test device for two concepts. Handheld PCs and Palm devices were considered and of the wide variety of those available at the time, the Hewlett-Packard iPAQ hx2495 Pocket PC was selected.

Wearable Concept 4 differs from 3 and 5 in that the central collection device is designed to immediately convey the data, through cellular service, through the internet, to a centralized database. Where the selection of the Bluetooth accelerometer was daunting in its lack of availability, the selection of a cellular phone and service were daunting as our effort had to consider a multitude factors: 1) identify the services available in Blacksburg, Virginia and that would allow for functionality throughout the remainder of the Commonwealth of Virginia; 2) identify a cellular-service provider that worked efficiently with the State's purchasing system (timely acquisition was a consideration); 3) identifying a cell phone that would work with the service and our devices. This last consideration was particularly complex. The phone would have to have a Bluetooth capability; it would have to have to be programmable (preferably Java); and, since Wearable Concept 6 seeks a cell phone with GPS to replace the external GPS device, the phone would also have to have a GPS device that was integrated and accessible (to programming). While the e911 mandate has influenced cell-phone manufacturers to produce cell phones with integrated GPS capability, there are few services that actually allow the owner of the phone to access the GPS chip. As it turned out, the company at the top of our list for service and phones provided us with two technology demonstrators: Nextel provided the Nextel Motorola i605 and the Nextel RIM Blackberry 7100i as well as the necessary services to facilitate our effort. In addition, Nextel has a rich line of enterprise applications designed for businesses to track their employees' cell phones and let employees share their location with fellow employees. As such, our effort had the opportunity to use their services within our research context.

One further note on technology availability: at the time of the writing of this report, Bluetooth-enabled devices with WiFi capability, cellular capability, and storage capabilities were just starting to become available. These would have been ideal to test; and when they become available with GPS, they may too serve the purpose of supporting Wearable Concept 6.

The Desktop concept will be addressed further below. In essence, however, it included a Dell Latitude running Microsoft XP and including Office XP. It was connected to the internet through a high-speed connection with a dedicated IP address. Any additional software installed on the machine was derived from the specific technologies our effort acquired, such as data extraction software for the accelerometer. Any additional software development, from the database to the web services to the automated uploading to the programming of the disparate wearable devices, utilized open source applications and forums. The choice for this was simple: as inexpensive yet workable as possible.

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[13] Oliveira, et al. 2006.

The individual technologies evaluated were either field (wearable) or desktop (analytical) in classification. Details on those acquired, configured, programmed, and evaluated in this effort follow.

Field technologies

Nextel Motorola i605[14]

Product description – Nextel Motorola i605 is a multifunction and rugged (US Milspec 810F) cell phone. The device used in this effort had an integrated GPS location capability, was Bluetooth enabled, was Java programmable, and could access the internet via the Nextel GSM cellular network. The device is depicted at right in Figure 1.

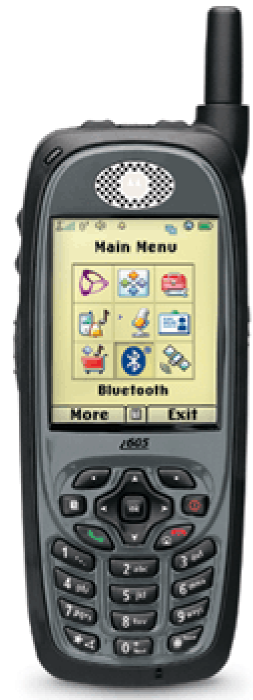

Figure 1 - The Nextel Motorola i605

Intended use – Wearable Concepts 4 and 6 called for such a device. In Concept 4, the device would collect data via Bluetooth from both an accelerometer and a GPS device and then retransmit it to a central server for storage and analysis. In Concept 6, the device would perform the same function but would transmit its own GPS signal in lieu of an external Bluetooth-enabled GPS device.

Actual use – Due to the inability to program this device as data transfer conduits, only a hybrid of Wearable Concept 6, and not Wearable Concept 4, was able to be supported by this device.

Cost(s) – $129.99 (i605) + $32.79/mo. (Nextel Free Incoming 300) + $ 21.99/mo. (TeleNav Track Premium) + $3.00/mo. (Public I.P.) + $10.00/mo. (Data Access) = $197.77 (for the first month) and $67.78 (for each month following)[15]

General comments – The strengths for this device are its ability to acquire, hold, and retransmit a GPS signal as well as its overall ruggedness. While the i605 is not as good as the stand-alone Bluetooth-enabled GPS devices examined in this effort, in particular in terms of spatial accuracy, signal acquisition and hold, it still performed reasonably well. The performance was good enough that one could still develop a very good picture of human movement through a regional space. The immediate drawbacks are its aesthetics, size, and weight. Its bulk could interfere with the daily routine of an individual, especially if there were other peripheral technologies involved along with using this as a central communications device. In addition, battery life was less than anticipated. However, its battery performed substantially better than the TrackStick and the Blackberry 7100i – lasting at least a day before requiring recharge.

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[14] The image of the Nextel Motorola i605 is from the Nextel web site: http://www.getnextelnow.com/Shop/SelectPhone.aspx?PhonePriceID=2658

[15] These figures are estimates based, in part, on the purchasing contract the Commonwealth of Virginia maintains with Nextel (for the service plans) and on the Nextel web site (for the device). Further, the Virginia Tech or the Commonwealth did not incur these costs as this device was loaned from Nextel to the Virginia Tech Transportation Institute as a Technology Demonstrator.

Nextel RIM Blackberry 7100i[16]

Product description – The Nextel RIM Blackberry 7100i is a multifunction device that serves as a personal digital assistant (PDA) and a cell phone. The device used in this effort had an integrated GPS location capability, was Bluetooth enabled, Java programmable, and could access the internet via the Nextel GSM cellular network. The device is depicted at right in Figure 2.

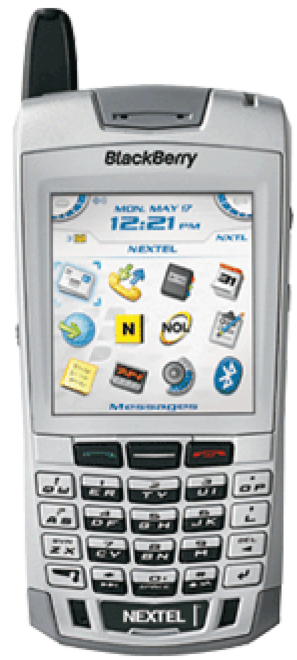

Figure 2 – The Nextel RIM 7100i

Intended use – Wearable Concepts 4 and 6 called for such a device. In Concept 4, the device would collect data via Bluetooth from both an accelerometer and a GPS device and then retransmit it to a central server for storage and analysis. In Concept 6, the device would perform the same function but would transmit its own GPS signal in lieu of an external Bluetooth-enabled GPS device.

Actual use – Due to the inability to program this device as data transfer conduits, only a hybrid of Wearable Concept 6, and not Wearable Concept 4, was able to be supported by this device.

Cost(s) – Cost(s) – $199.99 (i7100i) + $65.59/mo. (BlackBerry National Team Share 400) + $ 21.99/mo. (TeleNav Track Premium) + $3.00/mo. (Public I.P.) + $10.00/mo. (Data Access) = $300.57 (for the first month) and $100.58 (for each month following)[17]

General comments – The Blackberry 7100i is an attractive device with many capabilities that were not intentionally evaluated by our effort. Such attributes of aesthetics and personal functionality might prove useful in a future design where the central device being used to collect information is also intended to be a benefit to the participant. The device, while technologically fascinating, fell short of expectations on battery life (including the i605 and the iPAQ, this device had the shortest battery life when transmitting GPS data) and on apparent durability (it felt as if it needed to be cared for – seemingly low-grade plastics). However, when it was shielded in its holster and affixed to a belt clip, its relative flatness allowed the wearer to go about activities without noticing. Of course, if the wearer were wearing clothes without the need of a belt, placement might become more challenging – though, its performance (GPS acquisition and transmission) suggested that carrying it in a purse or a backpack would not be unreasonable. The caveat was that this device seemed to have a tougher time acquiring and holding a GPS signal than the i605.

16 The image of the Nextel Blackberry 7100i is from the Nextel web site: http://www.getnextelnow.com/Shop/SelectPhone.aspx?PhonePriceID=2573

17 These figures are estimates based, in part, on the purchasing contract the Commonwealth of Virginia maintains with Nextel (for the service plans) and on the Nextel web site (for the device). Further, the Virginia Tech or the Commonwealth did not incur these costs as this device was loaned from Nextel to the Virginia Tech Transportation Institute as a Technology Demonstrator.

Hewlett-Packard iPAQ hx2495 Pocket PC[18]

Product description – This device is classified as a handheld, or pocket, PC. While diminished in performance, it has the capability to perform most tasks that a laptop or desktop PC using conventional operating systems. Ours was configured with an additional 2 GigaByte (GB) Secure Digital (SD) memory card for additional storage. The device had an additional Compact Flash (CF) slot for additional hardware peripherals. This iPAQ also had Bluetooth and WiFi communications (802.11b) capabilities. The device is depicted at right in Figure 3.

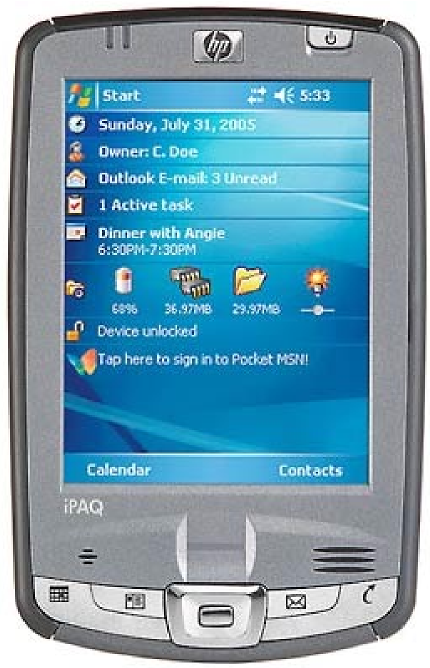

Figure 3 - The HP iPAQ hx2495

Intended use – Wearable Concepts 3 and 5 called for a third device to store and send collected data respectively.

Actual use – Due to a communications problem with this device and the local 'friendly' network (a Virtual Private Network (VPN) connection was unable to be established and therefore automation of the data collection and dissemination process was not feasible), Wearable Concept 5 could not be evaluated. Therefore, this device served as the storage device for Wearable Concept 3 only.

Cost(s) – \$419.99 (iPAQ) + \$69.65 (2GB SD card) = \$489.64

General comments – The GPS/PDA combination worked well with a messenger-style bag with the GPS unit attached to the shoulder strap and the PDA inside the bag. The PDA is a bit large/heavy/awkward when carried in a pants pocket. There have also been a few instances where the power button on the PDA was unintentionally pressed in the both the bag and pocket, this problem was corrected by moving the PDA into its own section within the bag and removing anything else from the pants pocket.

The device did require a great deal of configuration just to achieve Wearable Concept 3's design requirements. First, the device needed to be configured to communicate with a Bluetooth-enabled GPS; second, and more challenging, this device needed to be configured to store that information in a data logging fashion; third, the device would need to be connected to a host PC to download the data. The first and third steps were relatively easy to accomplish. However, the second task required a third-party application to be installed on this device. For this project the data logger developed by KRMicros was used to record the data.[19]

The iPAQ was not designed as a ruggedized device. As such, the user must treat it like the fragile computer it is; it is not water resistant and it does do well with temperature extremes. Addressing such flaws, as well as making it a smaller, would make this a very attractive candidate for field use.

[18] The image of the Hewlett-Packard iPAQ hx2495 Pocket PC is from the HP web site: http://www.shopping.hp.com/webapp/shopping/store_access.do?template_type=product_detail&product_code=FA674B%23ABA&jumpid=in_r329_personalization/browse1/landing_PDP&promo=1

[19] Handheld PC GPS data logging software is available at http://www.krmicros.com/Utilities/DataLogger/DataLogger.htm

GT1M ActiGraph[20]

Product description – This device is a wearable accelerometer and data logger. An accelerometer detects shifts in acceleration. In this instance, the device can be used to measure human motion in one dimension. Thus, when affixed to an individual's waistline, (e.g., belt) the device can measure acceleration along that plane. In such a capacity it can capture information on an individual's gait and serve as a kind of pedometer (measuring step frequency). The device is depicted at right in Figure 4.

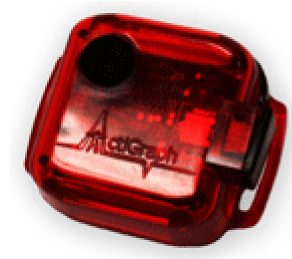

Figure 4 - The GT1M Actigraph

Intended use – Wearable Concept 1 called for a data-logging accelerometer to serve as either a pedometer or a device to measure gait characteristics. The GT1M served that purpose.

Actual use – Due to the inability to acquire a Bluetooth-enabled accelerometer, the ActiGraph would serve Wearable Concepts 3 through 6 as a defacto Bluetooth-enabled accelerometer. If the USB connection on the GT1M were replaced with a Bluetooth connection, this seemed a quite plausible design possibility.

Cost(s) – $399 (device) + $3 (connector cable) + $300 (ActiLife software) = $702 (it should be noted that one could have more than one device associated with one license/instance of the software)

General comments – In terms of the hardware and its ability to collect data, our effort was very pleased with the GT1M. It was small, rugged, water resistant, and lightweight. It was so convenient to carry on a belt that our testers frequently forgot they were wearing the device. This has tremendous benefits when conducting such a survey as it removes impedance from daily activity. However, clothes that do not require a belt might prove problematic.

The device was also impressive when it came to its ability to remain 'active' – that is, when recording data at its most frequent setting, the device had memory capacity and battery capacity to continually operate beyond a 24-hour period. This was better than any other device our group tested. It was also fairly easy to connect the device to a USB port for data download and recharging.

The device did have its drawbacks, specifically the software that came with the device. Establishing the software connection between the host computer and the GT1M was often troublesome. Configuring the device once a connection had been established was also undependable; our group had a great deal of trouble with the time-to-start feature.

[20] The image of the GT1M ActiGraph is from the ActiGraph web site: http://www.theactigraph.com/

Bluetooth GPS Units: (a) Globalsat BT338[21], (b) SYSONCHIP SMART BLUE MINI[22], (c) Holux GPSlim236[23]

Product description – Each of these devices are:

- GPS receivers using the SIRF Start III chip;
- Capable of transmitting GPS information via Bluetooth technology;
- Stand-alone devices that contain an internal, rechargeable, battery.

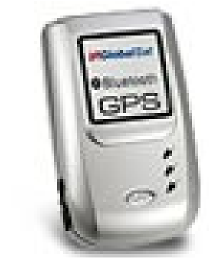

Figure 5 - The Globalstat BT338

Intended use – Wearable Concepts 3, 4, and 5 all called for the use of a Bluetooth-enabled and independent GPS device. Though markedly similar, and containing the same GPS chip (which had been selected as being the most accurate retail GPS chip), the external encasement, the battery and its life, were expected to vary somewhat. The Globalstat BT338 is depicted upper right in Figure 5. The SYSONCHIP SMART BLUE MINI is depicted middle right in Figure 6. The Holuz GPSlim236 is depicted lower right in Figure 7.

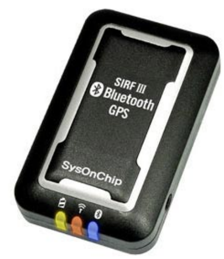

Figure 6 - The SYSONCHIP SMART BLUE MINI

Actual use – Due to the inability in the allotted time of this effort to successfully program the phones to connect to the Bluetooth devices and retransmit their data to a central server, these devices were only used in the case of Wearable Concepts 3 and 5 where they were paired with the HP iPAQ.

Cost(s) – (a) $121, (b) $166, (c) $108

General comments – These were very impressive devices. They exceeded our expectations on their ability to acquire and hold a GPS signal where other devices have historically failed. When used on our field trips the device in a car, it could be left on the dash or in a cup holder, on the person, strapped on a belt (using rubber bands), strapped onto the shoulder of a backpack (using rubber bands), left in an outer pouch in a backpack, or placed in a pocket. All this worked as long as the individual was outside and in fair weather. If inside, and in an outer room with large windows, the device seemed capable of acquiring GPS signals.

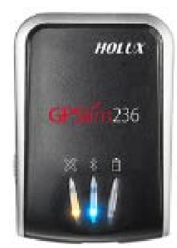

Figure 7 - The Holux GPSlim236

Packaging was adequate for placement on car dashboards, or in exterior backpack pockets in fair weather. However, it was not adequate for direct exposure to water.

As to device maintenance, plugging the devices in for power recharging was simple enough. Collecting data from them to the data collection device was easy as well, and so long as the data collection device had a contemporary operating system and had Bluetooth, establishing a connection was fairly easy.

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21 The image of the Globalsat BT338 is from the manufacturer's web site: http://www.globalsat.com.tw/eng/product_024_00001.htm

22 The image of the SYSONCHIP SMART BLUE MINI is from the manufacturer's web site: http://www.looket.com/

23 The image of the Holux GPSlim236 is from the manufacturer's web site: http://www.holux-uk.com/Products/gpslim236/index.shtml

TrackStick GPS Data Logger[24]

Product description – The TrackStick GPS Data Logger is a device that logs a GPS signal at some predetermined rate. The device is depicted at right in Figure 8.

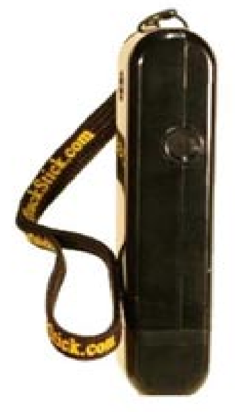

Figure 8 - The Trackstick

Intended use – This device was intended for use in Wearable Concept 1 as a wearable companion to a data-logging accelerometer.

Actual use – The TrackStick was used as intended in Wearable Concept 1.

Cost(s) – $258

General comments – The TrackStick, out of the box, held appeal because of its simple, compact, and seemingly convenient design; it looked as if users could immediately put it in their pockets, attached it to their belts, or sling it in their backpacks. Real-world use, however, revealed that the device had many shortcomings: GPS signal acquisition took a great deal of time; enabling the device to acquire a GPS signal took a great deal more effort than the other GPS devices (orient the device toward the sky and wait 15 minutes); positioning the device for the GPS signal hold required the device to be constantly in clear view of the sky – not an optimal feature when carrying or conveying the device; the device's rugged enclosure was not as rugged as it seemed; when collecting GPS data at 1-second intervals the batteries would wear down in less than a day, and while this is adequate for daily use, the device did not have the ability to recharge internal batteries – changing the batteries required a good deal of effort; when it was necessary to download the data, while the software application was adequate, the device required the internal batteries to still have some charge (the USB port was unable to provide sufficient current to extract data).

These are significant drawbacks for a device being used in study of the movement of pedestrians, especially if the participant would need to maintain this device on a daily basis along with other devices. However, minor modifications to the device would make it very attractive: 1) making the device rechargeable via the USB connection; 2) improve the rugged character (make it water resistant); 3) replace the existing second generation GPS chip with a third generation, such as the SIFR Star III.

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24 The image of the TrackStick is from the web site: http://www.trackstick.com/

Desktop technologies

Product description: The central system was composed of more than one product. In general, however, it was a Dell laptop, Microsoft Windows XP OS, Microsoft Office XP, and additional software applications that provided functionality to the overall desktop design (such as a web server) or select wearable technologies (such as wearable technology specific communications software – to transfer data from one device to this system).

Intended use: The central server would automatically collect all data from all wearable field technologies, archive them, and make them accessible via a commonly used internet device. More specifically, the original concept for the database design was to create an integrated system that is easy to upload information in to and display the results. The components to this system included: a web server; a MySQL-driven database; a simple html form with a Perl backend to upload the GPS text files to the web server and input the corresponding data into a database; an html page incorporating the Google Maps API to present the data generated in XML from the database.

Actual use: Those components of Wearable Concepts 1 and 3 through 6 that functioned had their data downloaded to this location, massaged (put into a common format), uploaded to a database for storage, and made available via a web portal (not on Google Maps, however).

Cost(s): Estimated cost of a laptop (similar capability to the one our effort used): $2500. Estimated cost of a high-speed internet connection with a dedicated IP (slower yet similar capability to that of our effort): $100/month.

General comments – The entire development process of the desktop component was a series of trials and error. The original concept called for a web server. For this project Apache was chosen as the web server and MySQL as the database because of their freely available distributions. There were some issues in creating the proper file permission and configuring Apache, MySQL, Perl, PHP, and Apache Tomcat. Because of these difficulties a preconfigured bundle of Apache, MySQL, Perl, and PHP called XAMPP was used along with an optional extension for Apache Tomcat.

After the web server was finally configured, the next step was to create an upload script to allow file transfers from remote locations. The first attempt at this was to create a Perl CGI script, but the files would not transfer (this could have been a result of improper file permissions). The second attempt was with a PHP script using PHP's built in File Transfer Protocol (FTP) functionality. A connection was established between the client machine and the web server host but the test files were not transferred (this could have also been a result of improper file permissions). The files were successfully transferred from a client machine to the server using a standard FTP program.

The next part in the database creation was to establish a system of tables in MySQL to store the data. First, a user table was established to generate a unique ID for each possible combination of person using the devices, GPS, and intermediary device. Second, a main table was created to store the following information: user name; GPS device; intermediary device; unique user ID; date of data collection; time of data collection; combination date/time ID; latitude; longitude; altitude; use of an accelerometer; measurement from accelerometer.

Then, two tables were created to act as "dump" locations for extracting data from the text files, one for the GPS data and the other for the accelerometer data. A series of SQL scripts were created to load the data, make necessary changes/conversions, and update the main table with the proper information. A few issues/errors did arise in this whole process. The National Marine Electronics Association standard (NEMA-0183) data stream recorded from the GPS devices did not have any date information associated with it and the time information is recorded in Coordinated Universal Time (UTC), whereas the other devices are recorded the time information in Eastern Daylight Time (EDT). The NEMA-0183 data stream logs latitude and longitude in decimal minutes, whereas some of the other devices log latitude and longitude in decimal degrees.

Finally, to provide text file dumps for the system, each wearable concept had its own process for downloading (though, this was not the original intent).

- Data collected from the iPAQ and Bluetooth-enabled GPS (Hybrid Wearable Concept 3) were downloaded via a direct connection made to the iPAQ through a USB sync cradle connected to the central laptop. The file was a text file in NEMA-0183 format.

- Data collected from the 7100i and the i605 (Hybrid Wearable Concept 6) were done so through the Telenav application portal on the internet (the latest version of Internet Explorer is required, no other brand or version web browser will function). The downloaded files were in a MS Excel format and could easily be converted into a text format. The downloaded information was not in NEMA-0183 format, but rather only included: unique ID, time/date stamp, latitude, longitude, and geocoded nearest roadway address.

- Data collected from the TrackStick GPS (Wearable Concept 1) required the use of the application that was provided with the device. The proprietary software allowed for an extraction of data in Microsoft Excel format, which could easily be converted into text format. The downloaded information was not in NEMA-0183 format, but rather included: unique ID, time/date stamp, elevation, latitude, and longitude.

- Data collected from the GT1M ActiGraph accelerometer (Wearable Concept 1, Hybrid Wearable Concepts 3 and 6) required the use of the ActiLife application that was an additional purchase beyond the initial hardware. The software allowed the download of the data from the device into Excel format and could easily be converted into text format.

Conclusions and Recommendations

The conversations with international, national, regional, and local disparate discipline professionals clearly showed an interest in collecting information on the way people move through space. That is a more general statement than stating that there is interest in the way pedestrians move through space – which was the impetuous behind this effort. It turns out that pedestrians are of interest, but only as just one of the many modes of movement behavior that people assume. For example, transportation planners are interested in where all people move; how they (the aggregate) get from point A to point B; pedestrianism is just one way that people can get from point A to point B. Health and nutrition experts are interested in how much energy people expend in a given day, being a pedestrian is just one of the energy activity expenditures. Biomotion experts are interested in the movement of the anatomy of people through space, again, pedestrianism is but one form the individual being studied might take. Certainly there is an opportunity to classify things as pedestrianism, but the key here is this: these researchers, engineers, and academics are interested in the movement of *people*, not necessarily things like cars. But the study of people in the real-world (not in a lab), has historically been limited due to technological limitations. This has meant that there have been restrictions on the ability to study people in the real world. In lieu of this capacity of study, some disciplines turned to peripheral representations of human movement, and to such an extent that these techniques of studies have become commonplace and dominant. Conventional transportation planning and engineering is automobile-centric. The ability for our cities to manage the relationship between land use and transportation frequently relies heavily on trip generation models that are associated with automobiles counts – not people.

With the awakening in the 1990s of a systemic view of the world, “develop for yourself a holistic view of some system,” transportation found a rational flaw in the study of the movement of people. Not everyone was being captured. Planes, trains, ships, and automobiles were being counted, but the other things were, for the most part, not. To compensate, suggestions were made to modify existing deployed techniques and technologies used for counting automobiles to count pedestrians and bicycles – to get the whole picture of human movement from point A to point B. This seems to be a half-hearted approach. All people know from experience, that when we walk, we often follow a near limitless set of rules and opportunities;

following the automobile's road network is not a primary rule. Thus, anything that is designed to capture the flow or movement of people will need to be as flexible.

Over the past six years technologies have evolved to such a point where the potential for disaggregate tracking of people from point A to point B has become possible. This effort attempted to develop deployment concepts and review select advanced technologies and techniques to determine what it would take to feasibly study the movement of people and provide information to multiple disciplines, but it proved to be challenging. This effort was only able to scratch the surface of what it would take perform such a deployment.

There are two interrelated components to this study: a technological concept and evaluation consideration component, and a social organization (knowledge and needs) component.

Technology

This effort initiated by reviewing a few very compelling wearable concepts. Transitioning to the real world left our researchers challenged with the number of technical variables that had to be addressed. Indeed, some of the findings of this report are cautionary notes.

- Configuration and programming of the desktop component, the WiFi device, and the cell phones took an inordinate amount of time and yet did not yield the expected results. The time spent attempting to configure and program these devices took as much time as the literature and the expert review combined. More than anything, this was due to the number of variables in the novel configurations our effort attempted to review.

- The purchasing of technologies to meet the initial technology concepts proved challenging. The most significant disappointment was the inability for our effort to acquire a Bluetooth-enabled accelerometer. Shifting the entire project forward into time a mere 6 months may have rectified this as technologies would have become available.

- The number of variables referenced in the bullet above can be found in the attempt our effort made to capture the details of the devices as they related to the human wearer, to each other, to the desktop, and intermediary components and systems. It seemed as if every time we looked at a part of the system, we would find new variables to study.

These comments on hurdles go to one cautionary note: when it comes to the number and type the technologies involved, simplify: the fewer the number and type of devices, the fewer the variables and challenges. Further, and this will be addressed in the section below, the stakeholders involved in such a project should also include a technical knowledge base in the use of specific technologies (such as an accelerometer or GPS or Java).

Despite these hurdles, the effort was able to capture some insight into some of the concepts. In Table 1 below, the initial wearable concept is compared with the evaluated concept; costs and number of devices worn and maintained (downloaded and recharged) are presented, as they proved critical.

Table 1- A comparison of initial wearable concepts as compared to evaluated concepts. *It should be noted that the cost of one wearable system and does not include desktop component costs.

Wearable Concept	Initial	As evaluated
1. Disparate data loggers	Data-logging accelerometer Data-logging GPS	GT1M Actigraph TrackStick Devices worn: 2 Device data download: 2 Device recharge: 2

		Cost*: $960 12 month total: $960
2. Data storage device wired to two collectors	Wired accelerometer Wired GPS device Wired storage device	*Not evaluated*: Too heavy, too large, too expensive, and inconvenient for a potential wearer.
3. Data storage device wirelessly connected to two collectors	Wireless accelerometer Wireless GPS device Wireless storage device	*Modification*: Wired accelerometer: GT1M Actigraph Wireless GPS devive: (a) Globalsat BT338 , (b) SYSONCHIP SMART BLUE MINI , (c) Holux GPSlim236 Wireless storage device: HP iPAQ Devices worn: 3 Device data download: 2 Device recharge: 3 Cost*: (a) $1313, (b) $1358, (c) $1300 12 month total: roughly $1300
4. Data conveyor wirelessly connected to two collectors	Wireless accelerometer Wireless GPS device Wireless data conveyor (cell phone)	*Not evaluated:* Unable to program phones to act as data conveyors.
5. Data conveyor wirelessly connected to two collectors	Wireless accelerometer Wireless GPS device Wireless data conveyor ("friendly" WiFi access)	*Not evaluated:* Unable to program device to communicate with "friendly" network.
6. Integrated conveyor and one collector	Wireless accelerometer Wireless GPS enabled data conveyor (cell phone)	*Modification*: Wired accelerometer: GT1M Actigraph Wireless data conveyor: 7100i and i605 Devices worn: 2 Device data download: 1 (for the wearer – the GT1M), 1 for the researcher – the cell phone) Device recharge: 2 Cost*: 7100i mo. 1: $1003 7100i mo. + 1: $101 i605 mo. 1: $900 i605 mo. + 1: $68 12 month total: 7100i: $2109 i605: $1646

The above table does not reflect the desktop component. Nor does it reflect the researchers or the facilities in which the desktop or the researchers are housed. There was an assumption that these things were already on hand and funded.

Before using these technologies this effort determined that the things worth evaluating were concept cost, data accuracy, and component size and weight. After using these technologies, our assessment focused on cost, consistency, and convenience. Cost remained of interest because the fees associated with each device were still relatively significant. Studies performed by Virginia Tech on physical activity focused on using a pedometer and a hand written log by the participants.[25] The technology budget allotted $25 per participant for each pedometer. Our individual systems were substantially more expensive. However, tracking does eliminate some user and researcher bias.

[25] Communications with Kathy Hosig in Spring and Summer, 2006.

Data accuracy was out because, for these products, there were other efforts that had evaluated accuracy. The GT1M Actigraph has demonstrated its accuracy and relevancy.[26] The Bluetooth GPS devices with the latest generation of GPS chips have also been documented as being accurate, and for the purposes of planners wanting to know where in a region someone is, they are more than sufficient.[27] The cell-phone GPS devices have also demonstrated their ability to provide accurate positional information.[28] The TrackStick data logger, however, had not been tried in research papers. Thus, what our effort might keep in mind was the ability to consistently provide data.

Size and weight were inherent in our effort's revised view of the technologies. Convenience subordinated size and weight. For the wearer/participant, convenience meant: how many technologies do I have to juggle and how many devices do I have to plug in and for what purpose (recharging goes to battery life; data download goes to complexity of process)? Convenience for the researcher was similar, but it was more attuned to how easy was it to collect data and review it.

There are some important considerations to keep in mind when reviewing our effort's work:

The evaluated version of Concept 3 likely proved the best in data collection. Interestingly, this design, specifically the arrangement of the architecture as worn on our evaluators, was similar to that arranged in by Oliveira, et al.[29] Our informal comparison between cell-phone-GPS and Bluetooth-GPS devices revealed that the Bluetooth GPS could provide more consistent GPS data – there were more frequent updates (every second) and the signal was held even with some obstructions (heavy foliage or indoors in exterior rooms). However, there were significant drawbacks. This system is still relatively inconvenient. The wearer must juggle three devices. The wearer/participant must charge three devices. The wearer/participant must download data from one device. Such a routine might lead to a wearer/participant not wearing the device because it becomes too much of a hassle. Cost for one wearable system for 12 months would be roughly $1300.

The technologies in Concept 1, like Concept 6, were fairly easy to carry. Just in terms of weight, however, this was the lightest configuration. The convenience for wearing the equipment, however, cannot make up for the maintenance problems. The GT1M was fairly easy to maintain – plugging it in to download also meant plugging it in to charge, one act. The TrackStick, however, proved problematic. Downloading the data was one act, but replenishing its batteries required great effort relative to all other systems evaluated. Further, its inconsistency in GPS signal acquisition and collection made it almost incomparable with the others. Cost for one wearable system for 12 months would be $960.

With Concept 6, there were only two devices to carry. When it came to maintain the devices, the wearer need only plug in the GT1M once to charge and download data, and plug in the phone to charge, the data would be accessed virtually by the researchers. This ability alone – virtually accessing the GPS data – was a tremendous benefit. Not only could the researcher access the data virtually, they could view and save the data. There were certainly drawbacks to the phones, for example the relative bulk of the i605 and the relative poor battery performance of the 7100i, but both had characteristics that seemed to balance those traits out (the ruggedness of the i605 and the extensive user features of the 7100i). Cost for the 7100i system for 12 months would be $2109. Cost for the i605 system for 12 months would be $1645.

A final note on technology: for any technology deployment that seeks to outfit participants with technologies, the focus should be on:

- Removing the burden from the participants (as invisible from their daily routine as possible: fewer things to plug in, fewer things to process);

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26 Oliveira, et al. 2006.

27 E-mail and phone communications with Sean Doherty in Spring and Summer, 2006.

28 July 2006 communication with Helen Franks regarding Nextel's i605 and TelenavTrack Premium technology used to track emergency services personnel at Roanoke's Martinsville Speedway.

29 Oliveira, et al. 2006.

- Removing the burden from the researchers (less set-up time, less time attending to participants, less time attending to data massaging);

- Removing the burden from the sponsoring organization (lowering cost).

Organization: knowledge and needs

Any of the aforementioned technological concepts is technically possible – they are all based on existing technologies. They can become technically possible and feasible given the appropriate alignment of a supporting organization, virtual or otherwise: how much money or people power will one throw at a problem?

Recommending the appropriate organization for a deployment focusing on the outfitting of technologies to a body of participants is not appropriate or possible from this effort's vantage point. However, given the experience with this effort, there are a few comments that might prove useful for others to understand who may be organizing for a similar effort.

First, the group of stakeholders ought to also include individuals technically proficient in the components of the system. Our effort attempted to develop a system based on a premise of a small planning agency going about such a deployment. We were successful in identifying and communicating the disparate disciplines relative to data needs, but we put too little effort in identifying and communicating the disciplines that could configure and program individual components, such as programming Java, or expertise in GPS or accelerometers.

In addition, there is a very broad range of disciplines and organizations interested in the movement of people, in particular, instrumenting people and studying the results from real-world movement. For a new organization – a new project – the broad interest is there (enough to start a project), the technology is even there (given some minor modifications), but there appears to be imbalance in fiscal allocation. A very minor example: a health-and-human-nutrition study on human activity was given enough technology money for 10 pedometers – roughly $250. The budget for this effort was $5000. Admittedly, there is a difference between a deployment evaluation and a real-world study, but this can be an indicator for discipline sensitivity of appropriate allocation for technology.

Alternatives and opportunities

There are, of course, alternatives that could be further explored.

Evaluated Wearable Concept 1 consisted of the TrackStick GPS data logger and the GT1M ActiGraph wearable accelerometer. That system was the lightest weight of all of the concepts. It was, however, somewhat inconvenient: two things to download data from, two things to recharge. Also, the individual performance of the TrackStick was less than expected. In contrast, the GT1M's wearable performance was better than expected. Given the bare bones nature of both devices, one wonders why both have not been integrated and what are the challenges to 'build your own device'?

Evaluated Wearable Concept 6 consisted of the GT1M and the i605 or 7100i. While both were larger than the TrackStick, the i605 and 7100i individually served as two devices. Further, the i605 and 7100i facilitated an improved measure of convenience for both the wearer and the researcher. This system was very near ideal except for the cost. Removing the 7100i from the system, with only the i605 version of Concept 6, the cost becomes more reasonable. If the accelerometer had actually been Bluetooth-enabled, and the phone had been successfully programmed, this system would have assured that the wearer only charge both devices – the data captured automatically, archived, and ready for analysis. Pressing further with such an evaluation is seen as a primary activity beyond this effort: two easy-to-use and easy-to-wear devices. An alternative to that pursuit would be to seek a modification to the Nextel data collection application (TeleNav Track) to accept additional data streams from the phone and associate them with GPS points collected. With such a system, there would be no need for researchers to develop their own desktop components.

If one were to remove the GT1M from Concept 6 leaving only the i605, could the GPS data collected from the device provide sufficient information so as to satisfy various disciplines interests? With the evaluation done for this effort, i605 reporting was, at a minimum, at 1-minute intervals. This is more than sufficient for educating city planners as to the movement of people through a city. But would it suffice for other disciplines (such as biomechanics)? For example, replacing the accelerometer with the GPS to measure gait would require a very high reporting rate.[30] Presently, the maximum rate of collection with the i605, using an application this effort did not evaluate, is around 3 s. Apparently, any more frequent reporting has a significant effect on the device's battery life. Using such a device for gait analysis would likely call into question many other things, such as the device's specific positioning on the person (belt or chest?); what happens if the person uses the cell phone as a cell phone? Though there are hurdles, such application deserves further exploration.

Another opportunity would be to establish a relationship with a cell phone company to provide regional user location data. This has already been done but for automobiles.[31] However, it was not accomplished using the GPS-enabled location techniques now offered by companies such as Nextel, as such, individual tracks might not have been as accurate as they could have been. With cell phone companies providing tracking information, individual privacy is certainly a dominant issue. As with the effort involving automobile tracking (via cell phone), privacy could be maintained by removing personal information and providing unique identifiers for each track. However, part of the benefit of participant tracking goes to the categorization that occurs of the individual being tracked: gender, age, ethnicity, profession, etc. To access such information, perhaps, once the relationship between researchers and cell phone company had been well established, research funds could be used to offer cell phone users a benefit if they participate in a tracking study. A derivative of this would be to first contact a major institution who maintains a large number of such phones with a company such as Nextel. Perhaps, for business purposes, phones could be tracked, and with the consent of individual users, tracked beyond the context of work.

The goal of the project sought to develop an understanding of what would be required to undertake a wearable-technology pedestrian survey in order to establish the background necessary for proceeding with a real world deployment. The goal-associated practical objectives were to identify those who would be interested in monitoring pedestrians and develop and review architectures of wearable of technologies. The first finding in pursuing those who were involved and interested in the study of pedestrians was that of a shift from focusing on pedestrians to human movement in general. This shift was better suited for two reasons: 1) it facilitated the identification additional disciplines interested in the individual movement of a person through space; 2) the technological differentiation between devices that tracked humans in general and pedestrians specifically are merging; tracking a person walking and transitioning to other modes had become easier than originally anticipated when framing this project, therefore it was no longer necessary to focus on one mode.

Following the shift in terminology, the next finding revealed that those disciplines interested in human movement through a region are quite diverse, ranging from public safety, to biomotion analysis, to transportation engineering, to city planning, to business operations, and to health and physical activity. While each had its own unique level of detail it wished to capture relative to human motion through a given environment, each would benefit from a deployment that could provide real-world location and movement characteristics of an instrumented individual.

The wearable technologies this effort developed and evaluated included six wearable architectures and found that at least two, with some modification, would be worth further exploration. These two systems, given modifications, provide a balance in cost, data accuracy, data consistency, and convenience (size,

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30 Moe-Nilssen, R. 1998. A new method for evaluating motor control in gait under real-life environmental conditions. Clinical Biomechanics 13: 20-327.

31 Smith, B.L., H. Zhang, M. Fontaine, and M. Green. 2003. Cell Phone Probes as an ATMS Tool. *Center for Transportation Studies, University of Virginia*. Research Report No. UVACTS-15-5-79.

weight, device maintenance [number of things to download data from; recharge], and number of things to carry).

Additional work is recommended on exploring the costs and trade-offs associated with the modifications of the two concepts. After such work, a limited and trial deployment is recommended where there are few fielded architectures, fielded for an extended period of time, but inclusive of multiple disciplines. This would test the architectures in their ability to handle extended temporal and environmental stresses, and it would determine which disciplines might benefit the most from an extended deployment.

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Appendix B - Technologies (product web sites)

Actigraph GT1M - http://www.theactigraph.com/

Globalsat BT338 - http://www.globalsat.com.tw/eng/index.htm

Hewlett-Packard iPAQ hx2495 Pocket PC - http://www.shopping.hp.com/webapp/shopping/product_detail.do?storeName=storefronts&landing=handhelds&category=handhelds&orderflow=1&product_code=FA674B%23ABA&catLevel=1

Holux GPSlim236 - http://en.holux.com.cn/product/search.htm?filename=gpsreceiver_bluetooth_gpslim236_gg_ggtx.htm&target=gpsreceiver00&level=grandsonson

Nextel Motoroloa i605 - http://idenphones.motorola.com/idenProducts/phonesHome.do?phones=605

Nextel RIM 7100i - http://www.blackberry.com/products/blackberry7100/blackberry7100i.shtml

SYSONCHIP SMART BLUE MINI - http://www.looket.com/

TrackStick GPS Data Logger - http://www.trackstick.com/index.html

Appendix C – Literature review paper

Pedestrian Activity Measurement: A Review of the State of the Art and the State of the Practice

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Key words – pedestrian measurement, walking, physical activity, travel behavior, spatial analysis, wearable technologies, infrastructure technologies, CCTV, GPS

Supporting research includes: regional non-automotive facility planning, technological-based survey design and application, regional travel patterns, and mobile-wearable GPS and accelerometer technological applications.

Abstract: Recent research on the connections between the built environment and physical activity has highlighted the need for better measurement of walking as a mode of personal transport. Yet, measuring the extent of walking behavior in conjunction with spatial and network analysis is often limited by data collection. Existing research has relied on two major methods: walker (subject) self-reports and pedestrian counts made on trails across open ground. These techniques have their benefits, but they also have their drawbacks. Self-reports may be spatially incomplete and subject to social desirability bias; pedestrian counts limit observations to a sample set of point locations in the pedestrian network.

Recently, engineers have proposed and developed new technologies that are designed to track non-automotive usage. These new technologies, designed to be part of the road and sidewalk, offer opportunity to improve traffic engineering studies. Yet, these are still limited to sample locations, and where to place such stationary sensors also poses a problem. But perhaps the greatest concern for public health research is that pedestrian counts, no matter how they are collected, merely reflect facility usage—not about the extent to which individuals walk, where they walk, or what real choices they made in deciding their routes for given trips.

Conventional pedestrian surveys and the placement of pedestrian sensor technologies may be supplemented with another technique; generating a pedestrian-test subject survey and applying wearable technologies to enhance the understanding of pedestrian movement throughout a given region. Such an approach promises

to reduce subjectivity and self-reporting bias while still capturing the extent and location of the pedestrian activity of research subjects.

This paper examines the state of the art and the state of the practice in proposed technologies for measuring pedestrian activity. In this paper, we synthesize the research on existing technologies, and based on this review we develop a conceptual framework for evaluating the opportunities in technology application to pedestrian research and design. The conceptual framework includes the individual, streetscape, and regional scales of pedestrian analysis. The individual scale includes the pedestrian himself or herself: their movement alone is of interest. The next scale up is the facility, streetscape, and community scale, and it encompasses the immediate space about the pedestrian relative to a specific transportation facility, or facilities, such as a pedestrian at a crosswalk. Finally, the highest scale is that of the region, which is a large space typically defined by administrative and political boundaries in which the pedestrian acts.

Introduction

Measuring the influence of the built environment on physical activity is an important topic for urban planning. The topic is highly interdisciplinary, and planners have recently come to recognize the interconnections between planning and public health. Yet, measuring human movement interests many fields other than planning and public health, including civil engineering, ergonomics, bioinformatics, and even military science. This paper examines the numerous possibilities for measuring human activity across many disciplines in order to inform future studies of pedestrian activity in planning.

In this paper, we review of some of the more prevalent methods and technologies involved in measuring and monitoring pedestrian activity. Technologies for monitoring pedestrian activity are a special concern, including wearable and infrastructure technologies. We examine the technologies and methods, what they are used to measure, and who uses them. We synthesize the research across disciplines to draw together related trends in measurement, along with a brief description of the potential for integrated technologies.

A Framework for Analysis

The pedestrian measurement methods are classified throughout this manuscript according to two criteria: 1) the level of analysis and 2) the motivation for the measurement. The level of analysis reflects the scale at which researchers chose to examine activity—the "who" to measure at a variety of spatial scales:

- *Individual* – the pedestrian himself or herself: their movement alone is of interest.
- *Facility, streetscape, and community*: the immediate space about the pedestrian relative to a specific transportation facility, or facilities, such as a pedestrian at a crosswalk.
- *Region* – a large space typically defined by administrative and political boundaries in which the pedestrian acts.

The motivation for measuring pedestrian activity varies considerably according to discipline. Generally, motivations include the following:

- *Health and fitness* – research that seeks to describe or improve pedestrians' mental or physical condition
- *Safety* – research or application that seeks to describe or decrease the potential for injury to pedestrian(s)
- *Security* – research or application that seeks to describe or improve the pedestrians' state of feeling safe

- *Ease/Comfort/Satisfaction*— research that seeks to describe how a combination of design, context, and individual perception coalesce to make walking an accessible or inviting mode over other travel choices.

- *Movement* – research that seeks to describe the movement of a pedestrian through space. Movement studies attempt to capture mobility and access. Meyer and Miller (2001, 95) provide a useful definition of mobility and accessibility:

> Mobility: The ability and knowledge to travel from one location to another in a reasonable amount of time and for acceptable costs. Accessibility: The means by which an individual can accomplish some economic or social activity through access to that activity.

Studies of Individuals
Studies on individuals examine both how and why, or rather why not, movement is or is not occurring. Health and fitness of the walker tends to be the major motivation for this individual scale analysis, and many disciplines have an interest in the walker's health, including athletics, the military, biomechanics, and ergonomics. At this level, the interest is on the pedestrians themselves; how they move, often relative to a particular object (around a structure, such as a curb) or during a specific activity (running, for example) .

At the most basic (and common) level of individual measures, health studies have used activity diaries, a pedometer or an accelerometer, and pre- and post-test interviews as demonstrated by Anderson, Hagstromer, and Yngve (2005). However, activity self-reports often do not have enough detail for health and fitness studies, and self-reports are further subject to social desirability bias with interview subjects over reporting socially desirable behaviors, such as the extent and vigor of exercise. By contrast, the detail that can be captured on walking/jogging/running movement in a laboratory setting is substantially higher. However, these laboratory tests may fail to capture how people really perform when walking in urban environments as described by Mayagoitiaa, Neneb, and Veltinkc (2001) when experimenting with comparisons in accuracy between body mounted sensors and optical sensors.

Individual monitoring technologies range from very simple devices such as the pedometer to terrifically sophisticated technologies, such as optical motion analysis systems. Monitors are used for several types of measurements; including the kinematics of individual joints, respiration rates, heart rate, gait analysis (step frequency, step length, walking speed, stride width, vertical lift), perspiration, core body temperature, oxygen intake and carbon dioxide expiration, and caloric energy expenditure.

Portable accelerometers have also been used to capture data for gait analysis. These devices provide a greater level of accuracy than pedometers, but they are also more expensive. They have been used often in the lab, and are increasingly being used in the field. Smaller accelerometers may be placed on multiple parts of the body, including the hip and trunk. In this way, they can provide gather field data on gait and upper body motor control during walking as tested by Moe-Nilssen (1998).

The most sophisticated system for capturing detailed individual movement information has come from optical motion analysis systems, which are primarily a laboratory technology. These have become smaller in recent years, and their smaller size allows them to be relatively comfortable to wear. Multiple additional accelerometers and gyroscopes (one uniaxial seismic accelerometer and one rate gyroscope per body segment) can be affixed to the individual walker, primarily for biomechanics (Mayagoitiaa, Neneb, and Veltinkc 2001).

Additional technologies for outside the laboratory include global positioning systems (GPS) technologies. GPS has become an important technology for a variety of different measurement methods. Terrier et al (2000) compared a GPS-derived spatial position with the motion logged from a waist-attached accelerometer and found that the GPS device was able to capture sufficient detail to be comparable with the accelerometer in gait analysis. Demczuk (1998) conducted a military study that examined soldiers' physiological traits relative to their movements in the field in order to provide data for combat simulation.

The study measured energy expenditure, core body temperature, sweating rate, walking speed, heart rate, and expired air over a course using a wide variety of mobile sensors, including GPS data loggers.

For planners, the point of examining individual technologies is twofold. First, health and fitness studies do suggest that while some physical activity is better than none, more vigorous walking is better than slow walking in overall subject health. Individual self-reports may not be the best measures of activity vigor for a variety of reasons, including social desirability bias. Objective measures of individual movement improve the ability to measure how much exercise individuals get during their routine walking activities. Second, the methods from in biomechanical studies offer an example of how to design wearable technologies so that they are comfortable and easy for individuals to use either for monitoring their own activity levels or for collecting planning-related data.

The facility, the streetscape, the neighborhood, and the community

Planning and urban design both require information about pedestrian activity within a given facility or streetscape. Measurement issues concern the perception of the pedestrian (how do you feel walking along this space?), or their movement through this level of space (their flows, the number of pedestrians, etc.). Data collection methods include direct observation, interviews, virtual environments, audits, and closed circuit television technology (CCTV).

Direct observation means that a researcher watches pedestrians and logs their behavior. This can be a useful means of collecting information on pedestrians as it allows the observer to take notes on many characteristics at once, often while minimizing interference with the subjects. Information collected using this method includes simple counts of the number of pedestrians; how long they take to cross a road; whether they use cross walks; and sociodemographic information as described by Bennett, Felton, and Akçelik (2001). Direct observation has some significant drawbacks. A person can only take in so much information at one time, and subjects may alter their behaviors in response to a researcher taking notes and asking questions.

Direct observation has had a technological ally of late: networked CCTV systems. CCTV systems can monitor and record information on many points in the built environment, or just one point, over time. The information can be recorded, archived, and analyzed many times. CCTV allows viewing and noting many characteristics about pedestrian movement and behavior relative to the built environment, but they afford a more limited field of view. Sisiopiku and Akin (2003) performed direct observation of pedestrians via CCTV to examine the pedestrian behavior relative to select facilities. Sensory technologies like active and passive infrared can capture motion across a wider spatial range than CCTV. However, CCTV may be used in concert with infrared technologies, or with extensive computational modification, to create an automated mode sensor where imagery is analyzed to detect pedestrians, selected traits, and their behaviors. For example, Makris and Ellis (2002) used CCTVs oriented in a multi-camera video surveillance network with overlapping and non-overlapping fields of view to identify pedestrian routes and paths. CCTVs have also been used in classifying pedestrians for activating other technologies, such as crosswalk signals as demonstrated by Hakkert, Gitelman, and Ben-Shabat (2002).

Even so, CCTVs are not necessarily the best technical means for identifying pedestrians. Such systems were designed to provide an extension to the human capacity for observation, but CCTV alone does not record good imaging in poor weather. Dai, Zheng, and Li (2005) have shown that infrared imaging often fares better in such circumstances.

In addition to monitoring technologies, surveys have been extensively used to study activity. They are popular because of their flexibility to collect a wide variety of information about the respondent. The PAPI, Pencil and Paper Interviewing, is a basic survey format, where the researcher intercepts a walker and asks him/her questions. Handheld computers and GPS augment the PAPI so that interviewers in the field can record the exact spatial location and time each interview; data coding is done, for the most part, at the time of the interview. Wolf, Guensler, and Bachman (2001) have described how GPS and handheld computers also support the 'Computer Assisted Self Interview' techniques that allow survey subjects to administer their own survey without a researcher present.

In addition to measuring the amount of pedestrian activity, surveys and scales may be used to measure pedestrians' attitudes about the built environment. Both Mitra-Sarkar (1994) and Pikora et al (2002) explore the researchers' use of environmental audits to create a systematic measure of built environment qualities. All of these may similarly be augmented with GPS and closed circuitry. Moudon and Lee (2003) conduct an extensive review of the literature and methods used in environmental audits designed to quantify the built environment. Because they comprehensively cover walkability and bikability scales, and there is no need to repeat their work here except to draw out a couple themes. Jackson (2003) provides a reviews auditing research and finds it covers three scales:

1) Buildings and grounds – identifying the benefits and drawbacks of lighting, exposure to roads, grades of facilities, etc.;

2) Neighborhoods – the benefits of mixed land uses; and

3) Towns and regions – the benefits of natural light, ventilation, parks and gardens, physical activity, high densities and mixed use, etc.

For health research, the goal is to evaluate the individual's ability to be active at each of these scales. One audit-based study evaluated pedestrian spaces using several qualitative measures including safety, comfort level, and convenience on sidewalks and intersections (Mitra-Sarkar, 1994). Another example, the "Systematic Pedestrian and Cycling Environmental Scan" (SPACES) method audited walking/cycling surfaces, streets, traffic, traffic safety, overall aesthetics, and a subjective assessment made by the reviewer (Pikora, et al, 2002). In contrast, Isaacs (2000) uses a survey to query pedestrians about how they felt regarding the space they had just passed through. By connecting the survey to an audit, the researchers can validate or "ground-truth" the audit for a particular place or demographic.

Streetscape level evaluation tends to use these methods and techniques in combination. For example, Sisiopiku and Akin (2003) employed in tandem direct observation via CCTV and intercept surveys in analyzing the perceived ease of using a crosswalk. Moreover, CCTV and direct reconnaissance methods may similarly be used to create virtual walk-through environments for urban design and with visual preference surveys in either laboratory or focus group settings as a further means to discover pedestrian preferences.

The region

For the most part, the regional level of pedestrian activity measurement seeks to determine the aggregate amount of pedestrian travel within existing regional transport networks. Understanding pedestrian movement at this scale, unlike at the individual or streetscape scale, has required the development of instruments that allow researchers and practitioners to estimate pedestrian movement. Surveys collected at the streetscape scale are sometimes treated as a representative sample and then generalized to the regional scale.

Typically, pedestrian activity measurement at the regional scale feeds into mode choice and travel demand models. On the one hand, national datasets incorporate walking and pedestrian variables along with socio-demographic information. These datasets are identified by Sharp and Murakami (2004) and include the National Household Travel Survey; National Personal Transportation Survey; and American Travel Survey. They do not have route information, however. With these and travel demand data, Rajamani et al (2003), identify four different combinations of data that are possible in estimating the level, timing, and spatial distribution of regional pedestrian demand, including:

1) aggregate spatial data (traffic analysis and zip code) and aggregate socio-demographics information;
2) aggregate spatial data and disaggregate socio-demographics;
3) disaggregate spatial data and aggregate socio-demographics; and finally
4) disaggregate spatial data and disaggregate socio-demographics.

Disaggregate spatial data is comparatively rare for the regional level because it requires the quantitative representation, to as fine a level as possible, of the built environment. A unique example of this are the disaggregate spatial data sets developed by Song (2002). Some regions of the country, such as the Charlottesville/Albemarle region in central Virginia, have developed planimetrics. While this spatial set was originally developed as a digital repository for engineering sub-neighborhood site plans, the data have spatial coordinates for import into a Geographic Information System. However, planimetric data require extensive computer processing power (especially when examining larger regions) and researcher time dedicated to digitizing the data. In addition, remote sensing and LIDAR (light detecting and ranging) data similarly allow regional level analysis with streetscape scale detail. However, these data also require fast processors, and LIDAR data are expensive to obtain.

Similar to disaggregate data on the built environment, disaggregate socio-demographic data is also scant. Travel or activity diary data may be gathered on a sample of regional residents; their characteristics will then be generalized to regional residents on the whole. With a travel or activity diary, the subject completes a log of their daily activity relative to travel choices or health-related activities. Turner *et al.* (1998) and relate to trip origins and destinations, the trip lengths (in terms of time and distance) purpose, and trip frequency. From travel diaries, trip routes may be imputed using a network analysis software such as ESRI's Network Analyst or TransCAD. Alternatively, individuals may be asked to specify the route. Ideally, the subject completes the diary on a daily or moment-by-moment basis.

Two technologies facilitate travel diary collection and the study of pedestrian movement through the region. Handheld Global Positioning System (GPS) devices and cell phone tracking are two possible methods for monitoring pedestrian movement. Cell phones are an attractive option for gathering this information, as they are becoming nearly ubiquitous. In addition, many phones are now integrated with GPS signal reception capability. Smith et al (2003) acknowledge that aggregate cell phone tracking is already possible for determination of automobile traffic flow along select corridors. But for pedestrians, Kracht (2004) demonstrates that disaggregate cell phone tracking is less accurate with lower signal reception compared to GPS devices. Scherer and Evans (2004) used hybrid cell phone/GPS with fairly accurate tracking for a transportation security study.

Some form of GPS technology carried by a pedestrian can replace or supplement route reporting or estimation in travel diary data collection. This way, it is possible to collect route data without the subject needing to remember and log their actions, which can be boring and time-consuming. Most of the studies involving this type of route measurement, however, have been based on automobiles. Those tests that have involved pedestrians tended to examine on multiple modes and suffered some significant setback. In one multi-modal study, the GPS device typically was unable to hold an accurate signal when the pedestrian entered a bus (Kracht 2004). At the time of the study, the more accurate GPS devices were ungainly for a pedestrian to hold, especially if the device was designed to a lot of information (Wolf, Guensler, and Bachman 2001). Scherer and Evans (2004) were able to work around this problem in their transport security study, as the hybrid cell phone/GPS devices they used were able to capture detailed movement patterns and immediately transmit the data to an online database.

Conclusions: the Next Generation?

Given the diversity of motivations behind pedestrian activity measurement, it is unlikely that one set of monitoring technologies, data collection, or models will serve all purposes at all scales. However, it is possible to envision several possibilities of future, integrated techniques and technologies across a variety of scales and in combination with existing data sources.

For example, sensor fusion technologies that access widely deployed, overlapping, and non-overlapping, infrastructure-based sensors can detect and classify an object moving through a region's transportation network. To some extent, this is already done in some locations with automobiles. With autos, sensors detect license plate numbers, log them, assign them an encryption code, and track them through the road network with specialized sensors. This is done primarily along a single corridor to estimate travel time. As the sensory networks expand within urban regions, and as pedestrian detection algorithms become more accurate and are networked, similar tracking methods could provide movement information on pedestrians. Such a system could provide the standard count and classification data for urban design, but it could also provide 'near' origin and destination data and a trend analysis capability for security and commerce. If the network of sensory devices were expanded beyond the public infrastructure to include shared private infrastructure such as in hotels or in stores, then the origin and destination tracking could potentially become even more detailed. If integrated yet further with other technologies, such as the cell phone systems, precise origin and destination data for a large group would be possible. However, such precise and coordinated tracking of individuals poses some thorny privacy and ethical issues.

As we discussed, cell phone tracking is already feasible for automobile travel. The application uses either the GPS-enabled cell phone position, or the triangulation of the cell phone, with a GIS file of the roadway network. Algorithms then search for cell phones that are likely to be in automobiles. The method can then dynamically measure auto traffic volumes and flow along a given street (Smith et al 2003). If algorithms can accurately isolate automobiles from non-automotive traffic, it may be plausible to use the non-automotive residuals for pedestrian tracking. Combined with a GIS file of the pedestrian network, the residuals would measure pedestrian frequency and walking speed. Such a system might be adequate to provide pedestrian movement data at a regional and neighborhood scale.

In addition, Virginia Tech has been exploring the technical feasibility of a multi-discipline, multi-scale, travel/activity diary. The data collection effort would be structured along the following lines:

- **Individual – biomechanics/health/ergonomics** –gait and trunk analysis, stride width, vertical lift, step frequency, step length, walking speed, heart rate (derived), perspiration (derived), perspiration (derived), respiration (derived), core body temperature (derived), and caloric energy expenditure (derived))—relative to the immediate natural and built environment.
- **Streetscape** – who/what/when/where/why/how is the pedestrian moving relative to the built and natural environments. Examine the trip – start/end, O/D (trip type), trip frequency, socio-demographic characteristics of the individual. Examine the space – weather, geographical topography, crime, and aesthetics.
- **Regional** – this addresses the same question as the streetscape, but at a regional level.

Such a travel/activity diary would test multiple regions (different social, environmental, and built landscapes), with at least 100 pedestrian test subjects for at least a week in each season. This design vitiates against travel diary exhaustion and temporal limitations of previous travel diaries. The design also tests a number of technologies discussed in this manuscript, including:

- Accelerometers – to provide data on the individual's biomechanical movement, and compared with GPS data when available.
- GPS – to serve multiple purposes: 1) when signal and corresponding accuracy permit, to provide data on the individual's biomechanical movement; 2) to provide detailed data on the individual's location.
- GIS – to provide comparative layers for data collected from the GPS and accelerometers. Layers of interest include:
    - Planimetrics
    - Property ownership (from tax records) and zoning
    - Crime data
    - Social demographics
    - Weather

However, such an ambitious merger of technology and data collection presents both ethical and technological issues. Given the nature of the level of data capture, and the proposed temporal extent, individual privacy and comfort will certainly become an issue. Starner (2001 notes that such a travel/activity and wearable technology experiment must address both ergonomic and privacy issues to even be marginally successful. Additionally, other issues such as the health effects of wearing cellular transmitters are unclear. Human beings, unlike cars, are difficult to instrument.

By testing numerous technologies in several contexts, it may become possible that planners, fitness scholars, and biomechanists can work the numerous issues highlighted in this manuscript. For wearable technologies, challenges remain in designing instrumentation that captures the type, rigor, and location of physical activity; maintains a strong an accurate tracking signal; and is both safe and comfortable for the pedestrian to wear. Ideally, wearable technologies would also be useful to the wearer in providing route or destination information and self-monitoring for fitness. Together, the mix of technologies offers numerous possibilities and wild experiments for increasing our knowledge on pedestrians and the built environment.

Reference List

Anderson, C. B., M. Hagstromer, and A. Yngve. 2005. Validation of the PDPAR as an Adolescent Diary: Effect of Accelerometer Cut Points. *Medicine & Science in Sports and Exercise* 37(7): 1224-1230.

Bennett, S., A. Felton, and R. Akçelik. 2001. Pedestrian movement characteristics at signalised intersections. Paper presented at the 23rd Conference of Australian Institutes of Transport Research (CAITR 2001), Monash University, Melbourne, Australia, 10-12 December 2001.

Dai, C., Y. Zheng, and X. Li. 2005. Layered Representation for Pedestrian Detection and Tracking in Infrared Imagery. Paper presented at the 2nd Joint IEEE International Workshop on Object Tracking and Classification in and Beyond the Visible Spectrum (OTCBVS'05), San Diego, CA, 20 June 2005.

Demczuk, V. 1998. Field validation of an energy expenditure model for walking soldiers. *International Journal of Industrial Ergonomics* 22: 381-387.

Hakkert, A. S., V. Gitelman, and E. Ben-Shabat. 2002. An evaluation of crosswalk warning systems: effects on pedestrian and vehicle behaviour. *Transportation Research Part F* 5: 275–292.

Isaacs, R. 2000. The urban picturesque: an aesthetic experience of urban pedestrian places. *Journal of Urban Design* Vol. 5, No. 2, 145-180.

Jackson, L.E.. 2003. The relationship of urban design to human health and condition. *Landscape and Urban Planning* 64: 191–200.

Kracht, M. 2004. Tracking and interviewing individuals with GPS and GSM technology on mobile electronic devices. Paper presented at the Seventh International Conference on Travel Survey Methods, Costa Rica, 2004.

Makris, D. and T. Ellis. 2002. Path detection in video surveillance. *Image and Vision Computing*. 20: 895–903.

Mayagoitiaa, R. E., A. V. Neneb, and P. H. Veltinkc. 2001. Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems. *Journal of Biomechanics* 35: 537–542.

Meyer, M. D. and E. J. Miller. 2001. *Urban transportation planning: a decision-oriented approach*. Boston: McGraw Hill.

Mitra-Sarkar, S. 1994. A method for evaluation of urban pedestrian spaces. Ph.D. diss., *University of Pennsylvania*.

Moe-Nilssen, R. 1998. A new method for evaluating motor control in gait under real-life environmental conditions. *Clinical Biomechanics* 13: 20-327.

Moudon, A.V. and C. Lee. 2003. Walking and bicycling: an evaluation of environmental audit instruments. *American Journal of Health Promotion* Sep-Oct; 18(1):21-37.

Pikora T., F. Bull, K. Jamrozik, K. Knuiman, B. Giles-Corti, and R. Donovan. 2002. Developing a reliable audit instrument to measure the physical environment for physical activity. *American Journal of Preventive Medicine*. 23: 187-94.

Rajamani, J., C.R. Bhat, S. Handy, G. Knaap, and Y. Song. 2003. Assessing the impact of urban form measures in nonwork trip mode choice after controlling for demographic and level-of-service effects. Paper presented at the 82nd annual meeting of the Transportation Research Board, Washington, DC, 2003.

Scherer, W.T. and M.H. Evans. 2004. Capital Wireless Integrated Network (CapWIN). *Center for Transportation Studies, University of Virginia*. Research Report No. UVACTS-15-21-6.

Sharp, J. and E. Murakami. 2004. Travel Survey Methods and Technologies Resource Paper. Paper presented at the National Household Travel Survey Conference: Understanding Our Nation's Travel, Transportation Research Board, Washington, DC, 1-2 November 2004.

Sisiopiku, V.P. and D. Akin. 2003. Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data. *Transportation Research Part F* 6: 249–274.

Smith, B.L., H. Zhang, M. Fontaine, and M. Green. 2003. Cell Phone Probes as an ATMS Tool. *Center for Transportation Studies, University of Virginia*. Research Report No. UVACTS-15-5-79.

Song, Y. 2002. Valuing the Impacts of New Urbanism Features on Prices of Single-Family Homes: A Case Study of Portland, Oregon. Ph.D. diss., *University of Illinois at Urbana-Champaign*.

Starner, Thad. 2001. The challenges of wearable computing: part 1. *IEEE Micro* 21(4): 44-52.

-----------------. 2001. The challenges of wearable computing: part 2. *IEEE Micro* 21(4): 54-67.

Terrier, P., Q. Ladetto, B. Merminod, and Y. Schutz. 2000. High-precision satellite positioning system as a new tool to study the biomechanics of human locomotion. *Journal of Biomechanics* 33:1717-1722.
Turner, S., G. Shunk, and A. Hottenstein. 1998. Development of a methodology to estimate bicycle and pedestrian travel demand. Report 1723-S. Research Project Number 0-1723. Sponsored by the Texas Department of Transportation. Austin, Texas.
Wolf. J., R. Guensler, and W. Bachman. 2001. Elimination of the travel diary: An experiment to derive trip purpose from GPS travel data. *Transportation Research Record* No. 1768.

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