AGENDA-BASED BEHAVIOR IN PEDESTRIAN SIMULATION

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ABSTRACT
In order to construct a simulation that aptly characterizes pedestrian interactions in large-scale transportation facilities, it is necessary to consider the means to represent the requisite goals and activities of interest to specific individuals that act as primary influences in their navigation choice and other decision-making processes. As part of the Intermodal Simulator for the Analysis of Pedestrian Traffic (ISAPT), we have implemented an objective-based task agenda for pedestrians with priorities that are evaluated relative to factors such as resource availability, travel cost, relative level of need and estimated time to completion. Time-variant sets of such pedestrians, in turn, are configured to represent larger population groups.

Keywords: pedestrian traffic simulation, agent-based, task agenda, route planning.

1. INTRODUCTION
The broader decision-making processes of a pedestrian, as well as their momentary behaviors, are influenced by a number of factors, starting with low-level assessments based on collision avoidance and movement towards a waypoint target. When modeling interactions between pedestrians within a working facility (e.g., an airport), the practical choices pedestrians make in determining their course of action is highly dependent on their current goals and needs, relative to specific value judgments. These must be assessed by individuals dependent on resource availability, anticipated costs to utilize, and their current environmental conditions within the model.

The active pedestrian populations in a facility will correspond with one or more transportation sources, each of which may have several associated entrance regions. Upon initial arrival and at successive stages thereafter, pedestrians will review their current set of objectives and determine a prioritized course of action in route-based and conceptual terms. Their working knowledge of the available set of resource locations associated with the tasks involved (potentially augmented via information sources), along with the presently known state of the dynamic model conditions affects the relative ordering and prioritization of these activities.

This paper presents the approaches currently employed by ISAPT to model varied population-based groups, where each pedestrian maintains a unique agenda and periodically re-evaluates their goals in accordance with available time and resources. The paper describes the components which enable system definitions along with agenda-based behavioral response – which drive the emergent system dynamics of the simulation.

2. TASK-BASED AGENDA
ISAPT enables dynamic specification of the respective characteristics of a group of individuals within a set of one or more *populations*. Each pedestrian population is active over a specified time range during the simulation run, in accordance with real-world events. The attributes of individual pedestrians may either be pre-defined in a separate data file, or generated randomly via rule-basic logic and distributions that assign characteristics such as age, gender, personal needs, entry location, and agenda tasks. Timing intervals of pedestrian arrivals and departures to a facility may be configured to represent varied modeled intermodal sources such as vehicular traffic or light rail and correspond to different schedule-based observations (e.g. morning, mid-day, evening) – where a certain set of flights is available – or vary in accordance with holiday events et al.

The definition of a *task-based* agenda is intended to augment more realistic simulation by allowing each person to maintain a set of intended activities under active consideration. Higher-level planning processes must take into account the effective agenda list that includes a subset of potential resource-based tasks along with basic personal needs a person may want to satisfy (e.g. hunger, thirst, curiosity, restroom use). Each individual's agenda is generated upon their initial entry into the system – either as part of population-based generation, or as specified within trial data – for a given pedestrian ID (along with other attributes such as entry point and personal characteristics). The working agenda thus contains a list of objectives a pedestrian wants to accomplish during their visit, where each can be satisfied via one or more resource nodes located in the facility model. Up to 30 activities may be assigned to an agenda (per visit) from the list of possible activity types.

Tasks are configured with one of several *activity types* which may be travel-based activities (e.g. ticketing, baggage check, security, gate arrival, system exit), activities related to basic requirements (hunger, thirst, restroom, info et al.) or user-defined types that enable additional resources akin to those in a given transportation facility (such as a network access point). Each task is assigned an associated level of *need* (0..100) from a specified value distribution. This need represents a relative amount of service required, where a given resource has varied capacity to restore resource levels for up to five different needs, following an overall service time distribution. As an example, a vending machine would restore less hunger (or potentially thirst) needs than a visit to food vendor or restaurant. Provisions exist to accommodate a broad range of agenda affected by visitor type (e.g., traveler, non-traveler, worker), observed crowd-based flow and/or those related to certain time spans or known transportation modes.

Additional task attributes relate whether it is a `required` task (i.e. must be accomplished before exiting the simulation), marked *primary* (vs. *secondary* by default) in importance, whether it is part of a subset that must be done in sequential order, and if there are constraints on the system time(s) it can be performed. Tasks can also be marked as `procToNextReqd` (to immediately proceed to next required task marked as such), `noSecondary` (for a *primary* task that must be pursued before considering those of secondary priority), `timeFirstAvail` and `timeLastAvail` (system time range of resource availability, e.g. for GATEs or shops). Note that only *primary* tasks may be marked as *required*.

Pedestrians' current needs requirement levels – in conjunction with estimated travel and wait time to matching resources – determine the *prioritization* of tasks as the pedestrian plans their ongoing route. The impact of these factors is discussed further in Section 4. As travelers tend to have discretionary time prior to a flight's departure, they need not focus entirely on the most vital tasks and can choose to utilize other resources within a facility while en route. Beyond simply choosing to wait in a seating area, for example, pedestrians may consider less immediate concerns and choose activities such as shopping or obtaining a snack when reasonably sufficient time remains.

The generation of agenda tasks assigned to individuals within a population is enacted via XML-based definitions in the main experiment setup file. Each definition contains a named reference and task type (satisfied with corresponding system resources marked in the 3D facility model, i.e. HUNGER, THIRST, ENERGY, RESTROOM, CURIOSITY, INFO, TICKET_COUNTER, TICKET_KIOSK, BAG_CHECK, LUGGAGE_PICKUP, CAR_RENTAL, ARRANGE_TAXI, SECURITY, [departure] GATE, SYSTEM_EXIT, along with any custom user-defined types). The resource need level offered by a resource is specified using one of several distribution types and associated parameters.

Figure 1 shows a section of XML which illustrates how an end user can specify activities that will be assigned to pedestrians observed at a one entrance location, in conjunction with group characteristics for a certain population. When a task is selected for the pedestrian, that activity is assigned to their active agenda. Each task's settings can take on values defined in another section of code – which may be based on a variable – and/or randomly determined.

The first code segment establishes a macro-based activity variable definition for an information enquiry (INFO) task, which can be referenced as "`info_rnd`". When specified as a variable setting `<alt>`ernative in one of the system prototype definitions, this definition may in turn be referenced to enact part of the agenda settings by one or more populations. This code assigns a need level from a truncated normal distribution with a mean of 50, variance of 10, and lower and upper limits of 30 and 70, respectively. This activity is denoted as *required*, of *primary* task importance, and to be pursued in preference to any secondary task. There is no specific constraint on the range of time it can be performed. Once this task has been accomplished, however, the pedestrian will turn their attention to the next primary task in the agenda sequence.

The next section of code defines the pedestrian attributes and activities that may appear on the agenda of pedestrians that are instantiated at "`enter_node`" `D3`. The first assigned activity is enacted via the `info_rnd` definition noted earlier. Its chance of being assigned is 100%; therefore, every pedestrian in the population has an INFO activity added to their agenda. This is followed by a statement that directly defines a personal attribute flag indicating that the pedestrian does not currently have a ticket (`has_ticket` is `false`).

The statement thereafter randomly sets a *utility* variable value that can be used as a basis to choose whether the pedestrian will visit the kiosk, counter, or both as a part of their check-in activities. The actual check-in activities are then assigned by enacting [previously coded] activity definitions to their agenda depending on what the `utility1` variable was set to, via three select statements that follow. This approach readily permits the assignment of one of a set number of tasks based on discrete probabilities.

Once check-in activities are defined, another statement sets the `has_luggage` variable to true or false using the stated discrete probabilities, resulting in 70% of the pedestrians having luggage to check while the remaining 30% do not. If necessary (according to what `has_luggage` is set to), the activity for visiting the baggage check area will similarly be assigned or not.

Each pedestrian is now assigned a series of potential activities requiring satisfaction of personal needs (e.g., hunger) according to probabilities (i.e. 33% chance to receive each need-related task, 67% not to).

The actual level of each need is determined via prior `<activity_alt>` definitions. The final activity to be assigned to the agenda, in this example, is the mandatory need (100% chance) for them to pass through security.

```
<activity_alt>
    <alt name="info_rnd"  taskType="INFO"
     taskLevel="normal, 30.0, 50.0, 70.0, 10.0"
     primary="T" required="T" noSecondary="T"
     procToNextReqd="T" timeFirstAvail="0.0"
     timeLastAvail=""/>
  …
</activity_alt>
  …
<proto name="activities_entry1">
  <select var="enter_node"> <alt chance="100"
  value="D3"/> </select>

  <select var="activity"> <alt chance="100"
  assign="info_rnd"/> </select>

  <select var="has_ticket"> <alt chance="100"
  value="false"/> </select>

  <select var="utility1">
     <alt chance="10,20,70" value="kiosk_only,
     counter_only,kiosk_then_counter"/>
  </select>
  <select var="activity" based_on="utility1">
     <alt option="kiosk_only"
     assign="kiosk_rnd"/>
  </select>
  <select var="activity" based_on="utility1">
     <alt option="counter_only"
     assign="counter_rnd"/>
  </select>
  <select var="activity" based_on="utility1">
     <alt option="kiosk_then_counter"
     assign="kiosk_rnd"/>
     <alt option="kiosk_then_counter"
     assign="counter_rnd"/>
  </select>

  <select var="has_luggage"> <alt
  chance="70,30" value="true,false"/> </select>

  <select var="activity"
  based_on="has_luggage">
     <alt option="true"
     assign="bag_check_rnd"/>
  </select>

  <select var="activity"><alt chance="33,67"
  assign="hunger_rnd, none"/> </select>
  <select var="activity"> <alt chance="33,67"
  assign="thirst_rnd, none"/> </select>
  <select var="activity"> <alt chance="33,67"
  assign="energy_rnd, none"/> </select>
  <select var="activity"> <alt chance="33,67"
  assign="restroom_rnd, none"/> </select>
  <select var="activity"> <alt chance="33,67"
  assign="curiosity_rnd, none"/> </select>

  <select var="activity"> <alt chance="100"
  assign="security_rnd"/> </select>
</proto>
 …
```

Figure 1: XML activity spec example.

Use of XML files allows ISAPT to create an extensive variety of agendas. Table 1 shows an example of an agenda for a pedestrian departing on a flight. Although the agenda shown contains eight tasks, for a traveler it could be contain as many as 30 (an ISAPT system constraint). For instance, a traveler with only two tasks assigned may have already checked-in online before arrival and have no luggage to check, thus needing only to pass through security and reach their departure gate. The example agenda in Table 1 includes a secondary priority CURIOSITY task. The stronger the "need" for this task the more likely this pedestrian will be to explore available displays, visit shops or exhibits, sit by the window, or explore of parts of the facility that are marked as satisfying some level of curiosity. As with curiosity, both the pedestrian's need to satisfy their thirst and visit the restroom are not absolutely required and therefore will only be performed if extra time exists in their schedule.

On the simulation level, what drives activity assignment for a given pedestrian is their membership in one of several named *population groups* introduced to the simulation - where pedestrians marked as part of a certain group will be assigned their individual characteristics and agenda tasks in a similar manner to what has just been illustrated, resulting in. potential activities with needs level set via specified distributions et al. Several populations may be active within the system simultaneously, where each produces associated pedestrians across a certain span of time.

Table 1: Example pedestrian agenda list

Need level	primary	required	no second ary	proc. to next	Resource type
80	x	x	x	x	INFO
70	x	x		x	TICKET_COUNTER
100	x	x			BAG_CHECK
100	x	x			SECURITY
65					CURIOSITY
30					THIRST
10					RESTROOM
100	x	x			GATE

Figure 2 shows an example that establishes two populations within a simulation scenario entitled "facility test". The first population group, *pop_A*, will release 45 pedestrians into the system starting at clock time 0.0 with an interval between releases that follows an exponential distribution. The specific attributes and agenda for pedestrians in this population arise from their collective set of named `<proto>`types that are applied within the statements illustrated in Figure 1. The system will continue to introduce pedestrians to the system from *pop_A* until either all 45 have entered or the end time (`releaseT1`) of 6000.0 seconds is reached. *pop_B* is constructed in a similar way, although it different characteristics and will start its release later in the simulation.

```
<population name="pop_A"  count="45"
  releaseT0="0.0"  releaseT1="6000.0"
  release_distrib="exponential, 2.1, 97.0">
    <proto apply="activities_entry1"/>
    <proto apply="gender_group"/>
    <proto apply="airline_set1"/>
    <proto apply="luggage_general"/>
    <proto apply="activities_general"/>
</population>

<population name="pop_B"  count="70"
  releaseT0="2400.0"  releaseT1="8500.0"
 release_distrib="exponential, 1.43, 50.0”>
    <proto apply="activities_entry2"/>
    <proto apply="gender_group"/>
    <proto apply="airline_set2"/>
    <proto apply="luggage_general"/>
    <proto apply="activities_general"/>
</population>

<scenario name="facility_test">
    <population source="pop_A"/>
    <population source="pop_B"/>
</scenario>
```

Figure 2: Configuration of two pedestrian populations

3. TASK-PLANNING

In order to define the navigational structure and connectivity with available resources, the ISAPT system first takes as input a 3D model of the facility to be simulated that defines the architecture and layout. A set of interconnected *nodes* provide the basis for conceptual route planning within the 3D model, where adjacent nodes typically have incoming and outgoing links to neighbors on a directional graph. Each node consists of a physical location and extent (along with navigational bounds) and similarly acts as a waypoint for route decision making and coarse movement (see Figure 3). These nodes may be given additional properties that allow them to: 1) act as *resources* that provide a *service* pedestrians require, 2) enforce entry requirements, occupancy limits, etc., 3) effect line-formation changes to the graph, 4) maintain data for purposes of statistical analyses and user-directed pedestrian observations (Usher and Kolstad 2011). This set of node-based resources forms the basis for behavioral choices when pedestrians reach a decision point (e.g. a navigation branching point, or simply an upcoming node along the route), where they will review their present course of action relative to knowledge of the current system state and time remaining. The blue circles in Figure 3 represent connected nodes in proximity to an airport ticketing area with queue lines leading to kiosk and counter service resources.

While task prioritization schemes vary greatly across pedestrian models and related simulations, they share a primary goal in *routing*, in that their objective is to determine efficient paths from one arbitrary location to another. Simulation, computer gaming and robotics applications must assess the 3D model space in terms of its navigation potential, incorporating some means to represent space as a set of inter-connected destinations.

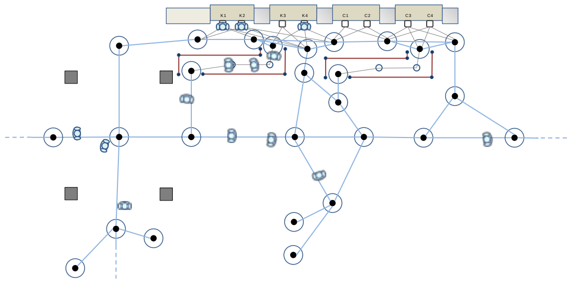

Figure 3: Portion of a connected node network model

In terms of path planning and traversal, determination of routes and respective travel cost/benefit in a simulated environment is largely dependent upon model representation. Grid-based pedestrian models (such as Kirchner et al. 2003) divide space into a set of uniform *grid cells* with inherent adjacency – thus a cell-to-cell route with minimal cost may be generated via iterative graph traversal e.g. the grid path maps of (Shao and Terzopoulos 2005), with perceived path *value* potentially influenced by prior traffic across those cells. 3D model space may also be evaluated to form a more general *navigation mesh* (O’Neill 2004) representing only the navigable regions of the model, which can be partitioned into a set of variably-sized polygons with shared boundaries that may be traversed. ISAPT is among the systems that employ a *waypoint graph* (Liden 2002) for path-finding, where navigable space is populated by nodes whose directional links have associated traversal costs (e.g. in terms of time and/or distance). Among well-known methods to find an optimal path among graph-connected nodes, a generalized form of Dijkstra’s algorithm (Knuth 1977) is utilized by ISAPT in determining shortest directionally-linked routes to all resource nodes of potential use for a given task.

When a pedestrian reaches navigational proximity to an upcoming graph node (per the orange-shirted traveler reaching the white outer node extent in Figure 4) the active (not yet completed) tasks on their agenda will have their current optimal routes assessed using that node as an origin point, considering paths directed towards any/all available resources that could satisfy the type of needs for each task. This re-planning may also occur in accordance when the pedestrian becomes aware of updates to current resources’ availability and/or anticipated wait times (including new opportunities nearby), changes in path connectivity, or updated information with regard to time constraints (e.g. the pedestrian may have just completed a task that took longer than expected and now find themselves behind schedule). This results in a time-based cost-value judgment (i.e. the associated cost weighted vs. level of current need, described in the next section) as to which potential destination works best. Therefore, the specific resource server node (and its route) the pedestrian aims for to achieve a given activity task can change as the simulation progresses. Once each activity has its most direct route determined and an associated acquisition value is computed, the pedestrian selects which activity and route to proceed with – potentially the same one as the present task in mind – and continues on their way.

Figure 4: Pedestrians traveling on central corridor route, considering resources nearby (via perceived benefit).

Although pedestrians consider their set of agenda tasks in the context of a prioritized list, this list simply acts as a basis for the decision-making process overall. In order to affect more complex behavior where individuals, for example, may choose to pursue an activity conveniently en-route, the primary/secondary status of each task is used to help guide consideration of which to pursue, taking into account its cost-value assessment. In accordance with observations of pedestrians in-situ, certain rule-based decision processes may be inferred as to how to manage tasks that differ in these respects. In the next section we will discuss prioritization strategies implemented in ISAPT e.g. where a pedestrian might choose to change their present course of action, or decide how to spend their spare time waiting for a flight via exploration of a secondary task such as visiting shop-related resources.

4. TASK PRIORITIZATION

When the initial activities are assigned to a pedestrian – and at every decision point they encounter thereafter – all active (i.e. not yet completed) tasks in the current set are evaluated. All resource server nodes *relevant* to a task [within range] are examined in terms of availability, estimated cost, and how well they satisfy the need. Though tasks are initially added to the agenda list in the order they are specified during population generation, there is no default requirement that tasks be performed in a specific order. Certain tasks may however be marked as requisite to complete in order prior sequence to others (per the `procToNextReqd` tag noted in Section 3). Research suggests that the conceptual tasks a person has will generally be re-considered on a habitual basis (Chen 2004) and that specific actions taken can enact a shifting of priorities on an agenda list. Effective changes in task scheduling (Joh et al. 2001) may occur when activities are added, completed, or change in accordance with temporal or spatial shifts in the environment (Bladel et al. 2009) which may enact an impulsive change to the currently planned task.

Upon reaching the next *decision point* the pedestrian will conceptually reflect upon their current (not yet completed) set of agenda tasks and re-evaluate them. In addition, changing system conditions, such as a resource node becoming available, may also trigger re-evaluation of a pedestrian's current tasks. If changing conditions are observed in their nearby environment that impact the pedestrian's estimates in reaching and/or utilizing given resource nodes – thus altering their perceived acquisition costs – agenda re-planning is triggered. This assessment takes into account the tasks' relative importance, the resource node's aptness for the task, and overall time required.

In many cases there will be one or more available resources for a given task that can satisfy it (to varying extents) in addition to resources that may be presently in-use but are worth waiting for. Resource availability may be observed in terms of node occupancy and anticipated wait time - to the extent that the resources are within "visual" proximity with respect to the pedestrian's current location. Estimated cost is computed as a time-based measure in terms of shortest travel distance (expressed as travel time) and time to acquire the resource (including estimated processing and queue wait time if a line exists). When an ISAPT node has the ability to restore multiple resource needs, these will be satisfied within the overall processing time. For purposes of task planning, the best-scored *available* resource (which may be currently *in-use*) that would satisfy task objectives is noted for each activity along with the optimal route path to that resource.

As a prototype expression inclusive of these factors:

$$\begin{aligned} Cost\text{-}Value = R_{importance} * \left(\frac{\min(R_{need}, N_{restore})}{100.0}\right)^{1.2} \\ * \left(T_{travel} + T_{queue\_wait} + T_{process}\right) \\ \left[* R_{primary} \text{ for primary tasks}\right] \end{aligned}$$

where $R_{importance}$ is the system priority weight for that type of task, R_{need} is the pedestrians current level of need, and $N_{restore}$, the amount a given resource node can resolve. T_{travel}, T_{queue_wait}, $T_{process}$ represent estimated travel time (at current speed), anticipated wait time in a queue and/or until the resource is free, and the typical service time at that node, respectively. $R_{primary}$ can be optionally set to enact greater preference for *primary* tasks independent of available time. Here, the overall time requirement weighs heavily vs. relative reward, akin to real-world considerations. The power of 1.2 is an initial value based on informal experimental trials.

Further experimentation and analysis is needed to determine an appropriate value and the sensitivity of system operation to changes in this number, along with modifications for observed preference with regard to time and/or distance.

After the next task has been selected (including its resource and route), if reason exists, the pedestrian's travel to that task may potentially be pre-empted prior to reaching the intended resource. For instance, if they pass near a water fountain that has become available and happen to be quite thirsty. The exception is when system conditions effectively "lock in" the task (e.g. when the pedestrian's agenda calls for tasks to be performed in-sequence or they have progressed partway through a queue line).

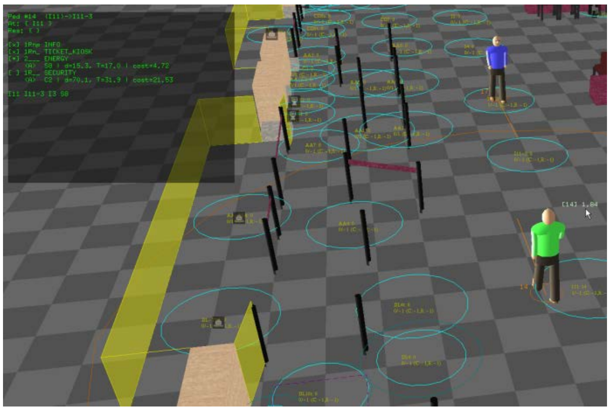

Figure 5: A pedestrian's working activity list after visiting a ticketing counter (heading towards seats)

While the pedestrian continues on their path and keeps track of their ongoing agenda list of tasks not yet completed (as seen in Figure 5 above), the decision logic that enacts the effective choice of task to be pursued must take into account some considerations beyond simply the raw cost-value assessment itself. Even though *primary* tasks are of more immediate concern, if an acceptable amount of spare time exists that would allow all required [and/or primary] tasks to be completed prior to facility departure, any secondary tasks that appear viable may also be considered for inclusion while en-route to the original task. For instance, a pedestrian might stop to get a snack or drink of water en-route to the ticketing counter or prior to entering a security zone on the map.

With these considerations in mind, the overall logic of pedestrians' activity choice can be roughly summarized as shown in Figure 6. Unless a pedestrian is occupied at a resource server, committed to a particular activity, or required to proceed with their next most immediate task, they will give priority to a certain course of action based on cost analyses of the available options. Primary tasks on the agenda will be reviewed if there are accessible resource nodes that at least partly restore the respective resource type. Certain nodes may not be reachable due to conditional requirements (e.g. a ticketing counter or boarding gate limited to passengers of a certain airline carrier and/or flight number),

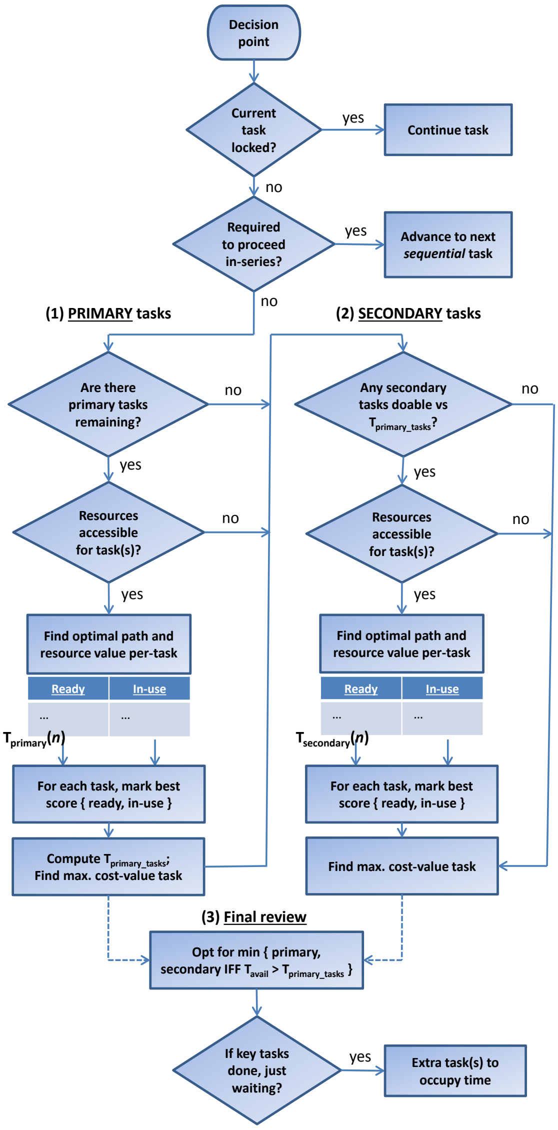

Figure 6: Task decision flowchart

temporarily blocked corridor regions, and other interruptions of graph connectivity. An optimal path is determined for each accessible resource and its cost-value computed relative to the resource needs level(s) that can be restored. In accordance with real-world pedestrian behavior, resource nodes are considered viable whether they are currently available or still being utilized – and periodically reassessed. The highest cost-valued task at that point becomes the working task choice.

As secondary tasks are viewed as optional, they will *not* be considered unless time estimates show time remaining beyond that necessary for all primary tasks' completion prior to the pedestrian's facility exit. Each secondary task will be checked for resource accessibility, followed by cost analyses, with a secondary task choice outcome if viable. While the cost scoring metric is the same for both primary and secondary tasks, an open primary task receives more immediate (and potentially weighted) consideration in the decision process.

Finally, where a pedestrian is not yet ready to exit the facility (e.g. when waiting to board a flight at their departure gate) yet has no other primary or secondary tasks remaining, they may opt either to continue waiting or add one or more time-occupying basic needs tasks of their choice (i.e. ENERGY (which may suggest taking a seat), CURIOSITY, HUNGER, THIRST, or RESTROOM) with randomly assigned levels. Incomplete tasks that remain on the agenda will take precedence otherwise. More detailed behavior in this case is not currently modeled in ISAPT.

5. SUMMARY/CONCLUSIONS

The ISAPT system facilitates structured definition of varied pedestrian populations for large-scale facilities, where individuals possess an array of characteristic personal attributes and activity interests that can vary in accordance with flight schedules, time-of-day variations, arrival source patterns and so forth – along with socio-demographic crowd distributions – as relevant trial data and/or larger research study trends may suggest. The associated tasks and priorities assigned to pedestrians within the mixed active population(s) allow users to explore the impact of these factors on resource usage and overall flow within the modeled facility.

As a key component of the simulation model, we have implemented a task-based agenda approach that allows flexible consideration of activity lists, where an individual may periodically re-assess their course of action in accordance with value judgments that reflect an ongoing reasoned choice of activities provided limited time to accomplish them. In sharing objectives with approaches that attempt to optimize working agenda lists' order via cost-benefit analyses applied to a collective task sequence in context of the surrounding environment (e.g. Hoogendorn and Bovy 2004), such strategies might be also applied to determine initial task order and/or to gauge current precedence for primary agenda tasks within ISAPT. However, incorporating less structured consideration of ongoing agenda while maintaining active preference logic has potential to provide a more free-ranging view of current agenda tasks, particularly where constraints exist but individuals may have larger periods of free time and/or be more apt to meander while exploring their surroundings.

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REFERENCES

Bladel, K.V., Bellemans, T., Janssens, D., & Wets, G., 2009. Activity Travel Planning and Rescheduling Behavior: Empirical Analysis of Influencing Factors. *Journal of the Transportation Research Board*, 2134, 135-142.

Chen, C., Garling, T., & Kitamura, R., 2004. Activity Rescheduling: Reasoned or Habitual? *Transportation Research Part F*, 7(6), 351-371.

Hoogendoorn, S. P. & Bovy, P. H. L., 2004. Bovy, Pedestrian route-choice and activity scheduling theory and models. *Transportation Research Part B*, vol. 38, no. 2, pp. 169-190.

Joh, C.H., Arentze, T.A., & Timmermans, H.J.P., 2001. Activity scheduling and rescheduling behavior. *GeoJournal*, 53(4), 359-371.

Kirchner, A., Namazi, A., Nishinari, K. and Schadschneider, A., 2003. Role of Conflicts in the Floor Field Cellular Automaton Model for Pedestrian Dynamics. *2nd International Conference on Pedestrians and Evacuation Dynamics*, 51-62.

Knuth, D.E., 1977. A Generalization of Dijkstra's Algorithm. *Information Processing Letters*, 6 (1): 1–5.

Liden, L., 2002. Strategic and Tactical Reasoning with Waypoints. AI Game Programming Wisdom. Charles River Media, Hingham, MA, 211-219.

O'Neill, J., 2004. Efficient Navigation Mesh Implementation. *Journal of Game Development*, vol.1, no.1, 71-90.

Shao, W., and Terzopoulos, D., 2005. Environmental Modeling for Autonomous Virtual Pedestrians. *Proceedings of the 2005 SAE Symposium on Digital Human Modeling for Design and Engineering*, Iowa City, Iowa, USA.

Usher, J.M., and Kolstad, E., 2011. Indoor Pedestrian Navigation Simulation Via a Network Framework. *Proceedings of the 23rd European Modeling and Simulation Symposium*, 247-253. Sept 12-14, Rome, Italy.