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# Transportation Planning and Scheduling for the 2014 Special Olympics USA Games

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The 2014 Special Olympics USA Games were hosted in New Jersey. More than 4,000 athletes competed in 16 sports hosted across 10 locations within a 30-mile radius. We designed timely, convenient, easy-to-follow, and reliable bus routes and schedules to assist thousands of people with intellectual disabilities and their coaches to attend games and special events over seven days under a budget of $600,000.

*Keywords*: transportation planning; crew scheduling; Special Olympics; mega event; genetic algorithms; vehicle routing and scheduling.
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Special Olympics is a nonprofit organization that grew out of Eunice Kennedy Shriver's observations of the unjust and unfair treatment of people with intellectual disabilities during the 1960s. The mission of Special Olympics is to provide access to sports training and athletic competition for children and adults with intellectual disabilities so they can achieve, succeed, develop physical fitness, experience joy, and be an active part of their local communities (Special Olympics, Inc. 2015). The global inspiration of all Special Olympic athletes is characterized by their powerful oath: "Let me win. But if I cannot win, let me be brave in the attempt" (Special Olympics: Our Athletes 2014).

The Special Olympics 2014 USA Games marked the third time the national games were held in the United States. The first was at Iowa State University in Ames, Iowa, and the second was at the University of Nebraska in Lincoln, Nebraska. In both games, events were held at one central location; therefore, an elaborate transportation system was not required. The 2014 Special Olympics USA Games were hosted by New Jersey in June 2014. More than 4,000 athletes and coaches from all 50 states attended, and the athletes participated in 16 sports over seven days. Unlike previous games, the 2014 USA Games were spread across 10 locations within a 30-mile radius in one of the most populous and busy areas in New Jersey. One key challenge was to design a convenient, simple, and reliable transportation system, which would operate on schedule for thousands of people with intellectual disabilities under a tight budget of $600,000. The total budget for the entire event was $15 million.

As with any sporting mega event of this magnitude, transportation and on time attendance were among the dominant factors to the success of the games (Beis et al. 2006). The 2008 Beijing Olympic Games avoided the transportation issues by constructing new accommodation and sporting facilities for most games in one central location at a cost of $44 billion (Pravda.ru 2008). With a meager budget of $15 million, new construction was impossible for the 2014 Special Olympic USA Games, and the games needed to be spread out to existing facilities. Thus, efficient bus routes and schedules had to be developed to ensure timeliness and convenience, considering 10 venues, four airports, and five special event locations, under a tight budget, and meeting the following special requirements.

- When serving individuals with intellectual disabilities, consideration must be given to avoiding long wait and travel times, and minimizing the number of bus transfers among routes; therefore, convenience has a significant role in transportation planning.
- The transportation system (e.g., bus routes) must be simple, easy to understand, cost efficient, and convenient. The system should also allow an outside constituent, such as a bus company, to easily execute and modify schedules, if needed.
- The system must be sufficiently reliable to handle unexpected events (e.g., random traffic patterns and disruptions) under a reasonable budget. This one-time mega event did not allow us to make any errors (from which we could learn during the event); thus, we had to plan ahead for any unexpected issues.

Commissioned by the game organizing committee (GOC), we designed and successfully implemented a transportation system that met these requirements. The system achieved 100 percent on time performance and 100 percent customer satisfaction, and it was on budget despite unexpected changes in participants' travel habits; thus, it contributed to the success of the 2014 USA Games. The system included both dedicated services for passengers whose timings and destinations were known, and shuttle-bus services to pick up random intermittent flows of passengers. The shuttle-bus services were costly and challenging; therefore, we developed an array of planning and scheduling models and tools ranging from demand-volume estimation and bus routing to driver scheduling, to strike a balance between effectiveness and simplicity for people with intellectual disabilities. These models and tools can be useful for future Special Olympics Games and other one-time mega-type events with dispersed locations and under a tight budget.

## Problem Description and Relationship to Literature

The 2014 Special Olympic USA games not only provided venues for the sports and competitions, but also abundant special events for education and family fun. Table 1 shows a high-level view of the schedule.

### Problem Description

The athletes and their coaches were disseminated to multiple locations for housing and the competitions. The College of New Jersey (TCNJ) and Rider University (RU) were the primary locations for housing (hubs). The games were hosted at TCNJ and RU, hubs 0 and 1, respectively, and eight other locations throughout New Jersey (Figure 1).

Table 2 shows the attendance for the games in each venue. Because of the multiple locations used for housing, competition, and special events, the GOC needed to provide transportation services to the athletes and coaches for the weeklong event. Transportation services can be divided into two categories: dedicated and shuttle bus services (Figure 2).

1. The dedicated services were provided to guarantee the pickup and delivery of athletes and coaches to events whose timings and destinations were known, such as opening and closing ceremonies, dinner cruises, and morning venues (every weekday from 6:30AM to 10:00AM). These events had known headcount and start and end times, allowing prearranged set times for transportation to and from events. Such services are also provided for those venues that are beyond the 30-mile threshold. The objective of such services was timeliness and reliability.

2. The shuttle services operated continuously in loops to pick up random intermittent flows, such

| Schedule | Saturday 6/14/14 | Sunday 6/15/14 | Monday 6/16/14 | Tuesday 6/17/14 | Wednesday 6/18/14 | Thursday 6/19/14 | Friday 6/20/14 |
|---|---|---|---|---|---|---|---|
| Games | No | Training | Yes | Yes | Yes | Yes | Yes |
| Special events | Welcome festival | Opening ceremony | Baseball, Olympic Town, Cruise | Baseball, Olympic Town, Cruise | Baseball, Olympic Town, Cruise | Baseball, Olympic Town, Cruise | Closing ceremony |

**Table 1: The competition and special events were spread over seven days for this event.**

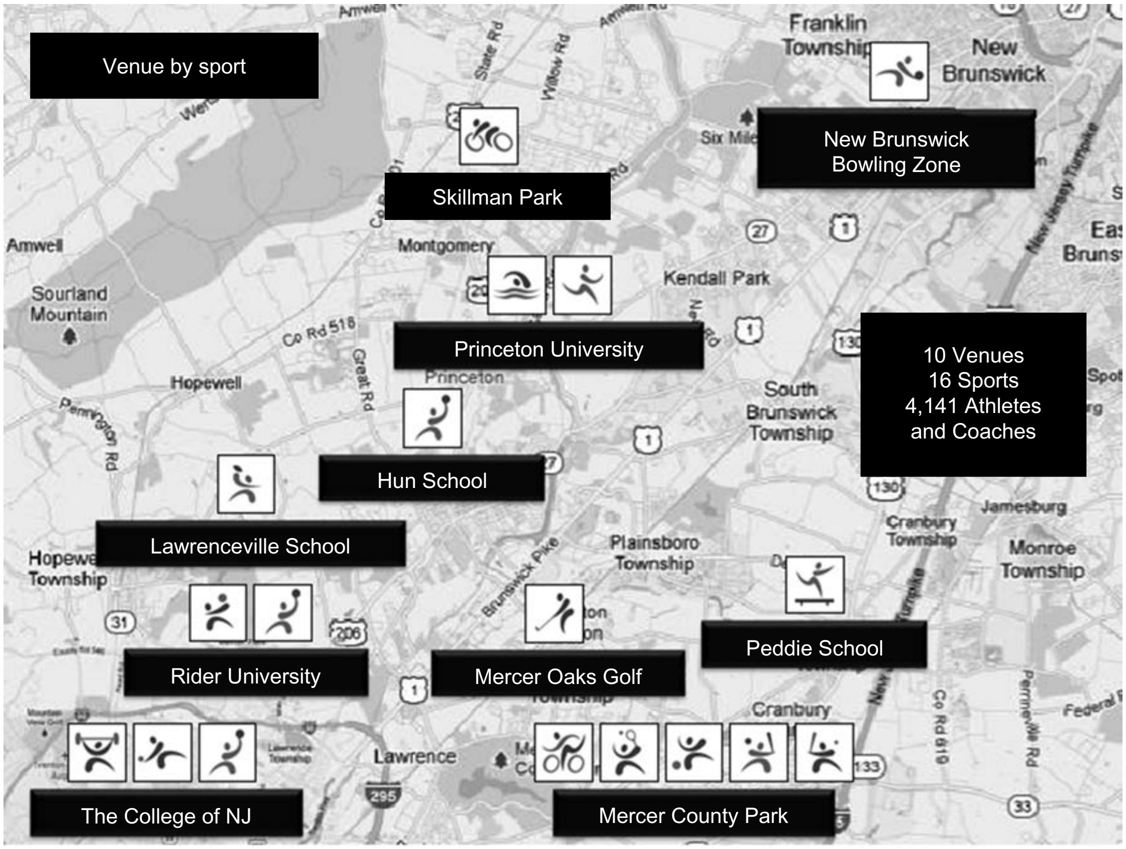


**Figure 1: The sports were hosted at 10 venues located within a 30-mile radius and in one of the most populated areas in New Jersey.**

as returning and sightseeing athletes and coaches from venues, traffic between hubs and Olympic Town (an amusement park) and Trenton baseball games, and pickup and drop-off services at airports (i.e., Newark Liberty International, Philadelphia International, Trenton-Mercer). The objective was convenience (e.g., short wait and travel time, minimum number of bus transfers), ease of understanding, and reliability.

| Venues | Attendance |
|---|---|
| The College of New Jersey (TCNJ) | 643 |
| Rider University (RU) | 427 |
| Princeton University (PU) | 945 |
| The Lawrenceville School (TLS) | 226 |
| Mercer County Park (MCP) | 952 |
| Mercer Oaks Golf (MOG) | 292 |
| Skillman Park (SKM) | 74 |
| Hun School (HUN) | 174 |
| Peddie School (PED) | 47 |
| Carolier Bowling Zone (CBZ) | 361 |

**Table 2: Each venue has a predetermined attendance based on the sports hosted.**

The planning of the dedicated services, which was based on the well-known taxicab problem (Giveen 1963), is relatively straightforward. The following equation shows the basic economics of dedicated services:

$$Number\ of\ buses = \frac{Number\ of\ riders}{Bus\ capacity}.$$

The most critical decision is the departure time for the dedicated services. Because some locations were 30 miles from the hubs and the region is highly congested, travel could take up to 40 minutes. An additional complexity was that 38 percent of competitors were part of team competitions. To ensure adequate capacity for this type of demand, a sufficient number

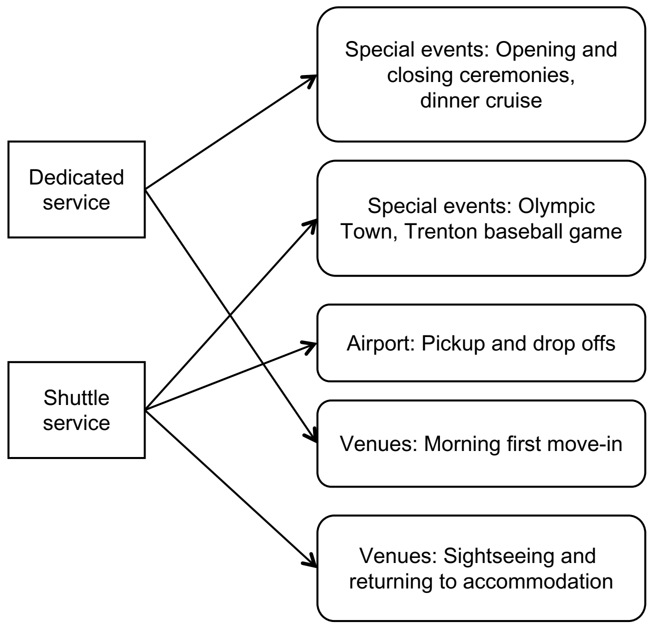


**Figure 2: We classified the transportation services into two categories: dedicated and shuttle services. The dedicated services had known timings, destinations, and headcounts and were used for time-critical events, such as opening and closing ceremonies and morning first move-in (i.e., morning venues). The shuttle services operated in loops to pick up random intermittent flows of people and were used for travel to and from Olympic Town, the Trenton baseball game, airports, and sightseeing.**

of buses needed to be available to transport entire teams.

The shuttle services, particularly for the returning and sightseeing flows (from 10AM to 6PM each weekday), was the most complex and costly part of the games' transportation system. The basic economics of a shuttle system is as follows: Given the time interval between consecutive shuttles and a route (loop), the number of shuttles can be calculated as follows:

$$\textit{Number of shuttles} \geq \frac{\textit{Round trip time}}{\textit{Time interval}}.$$

Each shuttle should have enough buses to transport every athlete and coach who arrives during the 20-minute time interval.

$$\textit{Number of buses per shuttle} \geq \frac{\textit{Time interval} \times \textit{traffic volume}}{\textit{Bus capacity}}.$$

Although calculating the shuttles and buses was simple once the loops (bus routes) were given, determining the loops and the driver schedule to minimize the passenger travel time and bus transfers, considering the budget constraint, was challenging. This is true for several reasons:

- The passenger volume was random and difficult to estimate.
- The routes had to include many locations (10 venues) and enormous combinations of loops, and scheduling the crew (the drivers) was complex.
- The system required a delicate balance among multiple performance metrics (e.g., travel time, transfers, cost efficiency, and simplicity).

### Relationship to Literature

Planning shuttle services includes traffic estimation, bus routing, and driver scheduling. It is closely related to the literature on public transportation planning and transportation-services planning for special events, which includes volume estimation, route design, and vehicle and crew scheduling (Ceder 2011).

The literature on travel-volume estimation usually empirically estimates origination-destination (OD) demand matrices using sophisticated statistics methods or stochastic processes based on historical traffic data (Carey et al. 1981), traffic counts and survey data (Lo et al. 1999, Cascetta 1984), or population-choice models and behavior theory (McFadden 1974). Route design is often modeled as a variation of the vehicle routing problem, addressing issues of travel time, waiting time, and transfers. Sophisticated optimization models and metaheuristics are developed and applied to large-scale public transit systems (Guihaire and Hao 2008, Desaulniers and Hickman 2007). The literature on scheduling problems that address vehicles and crews and drivers is abundant. The former assigns vehicles to trips in the transportation network (Bunte and Kliewer 2009); the latter determines staff schedules to meet demand in a cost-effective way (Ernst et al. 2004, Wren and Rousseau 1993).

Transportation in general can be complex, and planning for it is difficult (Desaulniers and Hickman 2007, Guihaire and Hao 2008); planning an effective transportation system for one-time mega events, such as the Olympics, can be more challenging (Beis et al. 2006). Frantzeskakis and Frantzeskakis (2006) document the transportation and traffic planning for the 2004 Athens Olympic Games. They describe the methods and software used to determine vehicle schedules for committees, sponsors, and media, based on game schedules and shuttle buses for spectators. The key insights obtained (for both the Athens and Beijing Games) is that spectator movements can be served well by a properly organized public transportation system.

Transportation services for the 2014 Special Olympics USA games were provided for athletes and coaches, had unique features, and required customized and novel solutions.

- Travel volume estimation. All previous Special Olympics USA games were held in one central location; therefore, large-scale transportation services were not needed. Thus, no historical data on participant travel patterns are available and we had no lessons on transportation services for Special Olympics from which we could learn. Without historical data, most sophisticated models in the literature cannot be applied, and estimating the sightseeing volume is the biggest challenge. Because of resource constraints, we were not able to conduct a large-scale sampling among participants; the exception was a simple survey, which we did among GOC members, about their likelihood of sightseeing. Utilizing the survey and the attendance and accommodation data, we built a simple model to detect the travel patterns among the venues and provided input and insights for efficient bus routing and scheduling.
- Shuttle routing. The games were characterized by a tight budget (funded by charity) and a high service-level commitment (required for people with intellectual disabilities). The service-level metrics included both conventional measures, such as transfers, travel, and wait times, and unconventional measures barely studied in the literature, such as the ease of understanding (simplicity). A shuttle loop with more than two stops could be regarded by GOC as too complex to follow. We developed a customized genetic algorithm (GA) to evaluate and optimize the shuttle loop. Inspired by the insights obtained from our volume estimation, we came up with a novel solution that provided direct shuttle services among venues with the highest travel volume, considering our budget constraints. This solution met all service-level metrics.
- Bus driver scheduling. Because the system had to serve people with intellectual disabilities, GOC mandated that the bus schedule match the erratic demand on each route. This requirement resulted in a new hybrid shuttle-taxi model, in which we had to account for both bus round-trip time, as in the bus-scheduling literature, and the driver-time constraints, as in the crew- and workforce-scheduling literature.

## Mathematical Models

In this section we focus on the shuttle services for the returning and sightseeing flows. We first built a travel-volume model to estimate the athlete and coach flows among the hubs and venues by day. We then evaluated and optimized the shuttle-bus loops to determine the sequence of venues to visit in each loop, while keeping in mind the unique challenge (i.e., ease of understanding) that the Special Olympic Games present. Finally, we designed the bus driver schedule to determine the number of bus drivers needed per shift on each route to meet hourly demand variation over a day.

### Daily Volume Estimation

Little historical data were available to allow us to research or to know, with confidence, the travel habits of athletes and coaches; therefore, we conducted a survey (Bixby et al. 2006) among the GOC members (e.g., chief operating officer and other members of the leadership team from the Special Olympics North America office), requesting the travel habits of the athletes and coaches from previous games; we particularly wanted to know their habits related to traveling to either a hub or nonhub (for sightseeing) once their individual competitions were completed. The survey, which took advantage of their combined experiences in organizing international and national games, indicated that 25 percent of participants would sightsee after their competitions. Based on the survey, we made the following assumptions:

- Everyone visits at most one other venue for sightseeing before returning to the hubs.
- The volume (of sightseeing) from one venue to another is proportional to attendance in both venues.
- Only a fraction of participants would travel between venues for sightseeing, and some participants live at hub 0 and others live at hub 1.

Given the number of attendees at all venues and their travel habits (e.g., probability of sightseeing), we split the daily returning and sightseeing travel volume among the venues and hubs into three parts: (1) sightseeing volume, (2) hub-returning volume without sightseeing, and (3) hub-returning volume after sightseeing. Clearly, the volume between two venues depends on whether the destination venue is a hub. If it is not, then the travel volume is only the sightseeing volume; otherwise, it is the summation of all the three parts. We refer the reader to Appendix A for more details.

Through a numerical study and robust analysis (by perturbing the probability of sightseeing), we constantly observed low volume among nonhub venues and from hub to nonhub venues, but significantly higher volume among hubs and from nonhub venues to hubs. Additional surveys indicated that athletes and coaches might prefer to return to the hubs for a change of clothes before going sightseeing, which further strengthened our observations.

## Bus Routing

To design an efficient and convenient shuttle-bus system to cover all hub and nonhub venues, we first developed a time matrix and then optimized the shuttle loops using the volume estimation we obtained in the *Daily Volume Estimation* section.

We initially constructed models using Google Maps® to collect travel times; these models served as a basis of the price analysis for bidding purposes. Six months prior to the event, the GOC and transportation managers developed an accurate representation of travel times by driving to and from each hub and nonhub venue using a motor coach bus.

For bus routing we determined the number of routes (loops), the venues covered by each route, and the sequence in which they would be visited. Because participants eventually return to hubs, all routes include at least one hub. We designed the routes to meet two conditions:

1. Completeness: Each venue must be included in at least one loop.
2. Nonrepetitiveness: One loop can visit a venue at most once.

The first condition ensures all venues are connected and the second removes redundancy in each loop. The objective of the shuttle-loop system is to minimize the weighted-average travel time and the number of bus transfers, considering our budget. The GOC mandated that the buses should be made available at each location (stop) every 20 minutes. Appendix A provides more details.

To build an efficient transportation network, we investigated multiple research streams in the vehicle and shuttle-bus routing problems. The bus transfer presented a technical challenge, because it renders integer programming models such as those with flow variables (Meng and Zhou 2014) inappropriate. To handle this challenge and the enormous complexity of the problem (the possible combinations of the routes and sequences are vast), we used metaheuristics—the GA. Nia et al. (2011) and Baker and Ayechew (2003) discuss GA applications in related problems. We designed a GA (Appendix B) to determine the set of routes to cover all venues, while optimizing the volume-weighted average travel time, the cost, and the number of bus transfers. Our testing showed that our GA found a high-quality solution more quickly than enumeration.

Using the GA and enumeration (Yih-Long and Sullivan 1990) whenever computationally feasible, we evaluated many options based on metrics of cost efficiency, convenience, and simplicity. The following options are representative.

1. Direct pairs: This simple option connects each pair of venues by a direct loop. This could be an expensive option, because the volume is disaggregated to each pair; however, it provides the maximum convenience with the shortest travel time and no bus transfers.

2. One loop for all venues: This simple option connects all venues by a single route. It aggregates the volumes on all pairs of venues to save money and requires no bus transfers. However, it may require lengthy travel times, because riders may need to make many stops before reaching their destination.

3. Two loops with seven venues: All loops include the two hubs and five other venues. This option is more complex, because the participants must memorize which loop serves which seven venues. The travel time and cost are between those in option 1 and option 2, and this option may require one bus transfer.

4. Three loops with seven venues: Each loop serves the two hubs and five other venues. It may decrease the travel time in comparison to option 3; however, it is harder to follow and may increase the number of bus transfers.

5. Two hubs and one nonhub: A loop covers the two hubs and each nonhub venue. It is simple to follow and ideal for the returning flows from nonhub venues to hubs; however, a sightseer at a nonhub venue may need to transfer to another bus at least once.

6. Direct hub and nonhub: A loop directly connects each hub and each nonhub venue. It is more expensive than option 5, but it results in shorter travel times and is easy to follow.

Table 3 shows the results from these options, including required budget and average travel times.

After we showed the results to the leadership team, GOC picked option 6 (direct hub and nonhub routes) based on its convenience, shorter travel times, and simplicity of comprehension for individuals with intellectual disabilities. The relatively small volume of sightseeing flow and the survey referencing athletes and coaches returning to hubs before going sightseeing eased the bus-transfer concern. Option 6 also met the budget requirement.

| Option | Budget ($) | Average travel time (minutes) |
|---|---|---|
| 1. Direct pairs | 418,545 | 16 |
| 2. One loop for all venues | 100,800 | 68 |
| 3. Two loops with seven venues | 144,000 | 32 |
| 4. Three loops with seven venues | 136,800 | 24 |
| 5. Two hubs and one nonhub | 142,335 | 25 |
| 6. Direct hub and nonhub | 153,945 | 23 |

**Table 3: Our genetic algorithm, which we labeled SO2014, computed the required budget and average travel time for each option and found that option 6 (direct hub and nonhub) provided the shortest average travel time without exceeding the budget.**

## Bus Driver Scheduling

To schedule bus drivers, we first disaggregated the daily volume into hourly demand, which we defined as the number of people needing transport per unit of time (hour). To this end, we had to consider the game schedule and lunch schedule; lunch is provided at each venue. We expected that participants of a game would stay until the game was over and then return to the hubs before sightseeing. In addition, if the game completed before lunch, people would leave after lunch. Finally, people might go sightseeing at other venues, and the timing would occur equally likely from the time they return to the hub until 5PM. The estimated hourly volume typically peaked right after lunch and diminished toward the end of the day (6PM).

Given the bus routes and the hourly volume estimates by day, we needed to determine the bus driver hourly schedule and the number of drivers needed per shift (Yoshitomi 2002). Each bus would depart from hub 0 or 1 to a nonhub venue and return to the same hub. Each bus would only serve one venue, and the number of buses used in each would vary over time.

We broke down hourly volume on each route into 15-minute time buckets (the actual time interval for most loops) and developed a mathematical programming model to determine which driver would take which route during which time bucket to meet changing demands over a day at the lowest bus driver cost. In addition to the demand constraints, we had to ensure that a bus driver works at least a specified number of consecutive hours (a typical time constraint for crew- scheduling problems), and that the bus driver is not available to serve a venue again until after the round-trip (a typical constraint for bus-scheduling

| Phase | Time frame | Structure | GOC feedback |
|---|---|---|---|
| 1 | Two years prior to games: Game schedule 60% complete | Shuttle-bus routes | Lack of travel habits, complex routes, not intuitive |
| 2 | Six months prior to games: Game schedule 95% complete | Includes travel habits to fine-tune volume estimation model, simpler bus routes (e.g., Options 5 and 6) | Option 6 selected based on convenience and ease of understanding |
| 3 | One month prior to games: Game schedule complete | Breaks down daily volume into hourly volume, and schedules bus drivers on each route | Adopted, enhanced by risk-management plans |

**Table 4: We implemented a three-phase approach, interacted repeatedly with the games organizing committee members to obtain the latest information and their feedback, and addressed their requests with new solutions.**

problems). Appendix B provides the detailed model formulation. We implemented the model using the Python programming language and the Gurobi optimization program.

## Implementation

The implementation process was challenging for several reasons: (1) much of the information that was critical was available to us gradually (Varelas et al. 2013); (2) many modifications were necessary throughout the planning phase (Bixby et al. 2006), such as fluctuated games budgets, game schedules, and venue adjustments; and (3) we had to prepare for numerous layers of risks and contingencies.

### Implementation Phases

We used an iterative implementation process and a three-phase approach (Table 4). In phase 1, approximately two years prior to the games, we estimated traffic volumes based on attendance at game venues and created shuttle-bus routes based on daily traffic volume, thus laying the foundation for our bid. In phase 2, about six months prior to the games, we conducted a survey and included the athlete travel-habit matrix, which significantly improved our volume estimation. We also studied simpler route options—options 5 and 6 in the *Bus Routing* section. Phase 3 incorporated the GOC leadership team's selection of the simple direct hub to nonhub routes (option 6) and scheduled the bus drivers to meet hourly demand.

### Bus Companies

Transport for the games was delivered through a partnership between the GOC and the Academy and First Student bus companies. Table 5 shows the vehicle

| Type | Capacity | Cost/Hour ($) | Total available |
|---|---|---|---|
| Motor coach | 50 | 90 | 300 |
| Low step | 50 | 75 | 10 |
| School bus | 45 | 54 | 100 |

**Table 5: Two New Jersey-based bus companies provided an estimate on the number of buses available, the capacity, and the cost per hour for each type of bus.**

types and capacities. The motor coach bus was used for competition, airport services, and special events, and the low-step transit bus was used for the shuttle services from the TCNJ and Rider venues. The school bus was used for the evening showcase sports and special events. By contract, the minimum time required to engage a bus was four hours for all services.

Once the competition and special event schedules were solidified and provided to the state delegations, Academy, and First Student, the GOC conducted a tabletop exercise to determine the number of buses needed. This proved to be very fruitful because it enabled us to identify potential problem areas and assign the number of drivers needed throughout each day.

Both transportation companies used the plan to schedule routes and the number of buses needed to transport the athletes and coaches to their respective competition venues and return them to their originating hubs. This information was critical for determining the number of buses they would need to add to their New Jersey fleets, because they provide services for the entire northeast region.

### Risk-Management and Contingency Plan

One challenge in hosting a mega event is that those responsible must do everything correctly the first time, because such an event provides no opportunity for learning (based on mistakes) and improvement during the event. Consequently, we had to identify all potential risks and contingencies and develop a robust transportation system. Therefore, prior to the games, we put together a list of common risks for a transportation network.

1. Traffic: The venues were scattered throughout central New Jersey, an area that is busy with its typical daily traffic. Coupled with the influx of new observers, we expected a driving-time increase of 20–50 percent during morning rush hours relative to non-rush hours.

2. Volume: The passenger volumes for all transportation services were best estimates based on game schedules and our understanding of travel habits. Overestimating can result in waste; however, underestimating can result in long wait times and poor customer service.

3. Technology: Various communication devices, such as radios, global positioning systems, cellular phones, and handheld tablets, which we would use in our transportation system, can malfunction or break down.

4. Weather: This event would be held during the summer; therefore, we would have to consider the probability of excessive heat and thunderstorms, possibly resulting in delays.

5. Driver error: The drivers are professional drivers from well-established bus companies; however, because of human error, some drivers might not arrive at the designated locations on time.

6. Route closures: Scheduled outages or unplanned accidents are always a possibility. Alternate routes would need to be identified and scheduled at the planning stage.

7. Mechanical: Vehicle performance, even with proper maintenance, can be affected by unplanned mechanical problems.

In response, we developed the following risk-management strategies. First, we reserved a small budget to enhance the reliability of the transportation system by pooling a fleet of extra buses at a few strategic locations to provide emergency services; this proved to be valuable during the games, because our hourly traffic prediction did not precisely match the peak demand. Second, the GOC developed a transportation risk-management plan with the assistance of the bus company operations manager. To ensure communication was cohesive throughout the multiple locations, a main operations center (MOC) was established at one of the campuses. The MOC, which represented several departments—including games transportation, the New Jersey Department of Transportation (NJDOT), law enforcement, and public safety—operated on a 24-hour schedule. To address transportation issues, the MOC contained multiple display screens connected to real-time global positioning system-monitoring and the NJDOT regional In Transit Visibility (ITV) systems. The benefit of using real-time and ITV monitoring was the ability it provided to track every bus in the network and the option to use alternate routes if needed.

## Results and Achievements

### Results

Special Olympics 2014 was the first USA game held at dispersed locations in a populous area such that it required large-scale transportation services. Our models and algorithms, together with an iterative planning and implementation process, resulted in a transportation system that was timely, convenient, cost efficient, easy to understand, and reliable. First, it provided a convenient 20-minute interval between consecutive buses and an average travel time of about 23 minutes over all pairs of locations. Second, the system provided easy-to-understand, one-stop services without the transfers; at nonhub venues, participants needed only to follow the color of a sign on the bus (i.e., red for RU and blue for TCNJ). Finally, it was cost efficient and reliable. It met the budget constraints and had a sizable surplus of $45,000 left over, thus allowing us to plan for contingencies.

The transportation system we developed may be applied to other one-time mega events held in sparse locations, such as Olympic Games, mega exhibitions, and conferences.

### Achievements

Despite unexpected travel-habit changes because of New Jersey's many attractions, the transportation system implemented for the 2014 Special Olympic USA Games was a great success. The system (1) was on budget; (2) achieved 100 percent on-time performance at competition, special events, and airports; (3) maintained an average of 20-minute intervals to all venues, as planned; and (4) achieved 100 percent customer satisfaction, based on random interviews of 20 athletes and coaches and observations by several hundred operation managers at bus stops.

As one coach we interviewed said: "Couldn't have asked for a better bus transportation system. Buses were on time and didn't have to wait."

### Implications

The study provides an approach that allows an event host to do more with less for mega events such as Olympics. The norm of the current practice is heavily geared toward the construction of large-scale multipurpose facilities (e.g., 2008 Beijing Olympic Games) to avoid a nightmarish transportation problem. The construction of such facilities, however, often results in large capital expenditures upfront and underutilization after the event. To avoid this problem, one can utilize existing facilities that may, however, be sparsely located. The success of the transportation system developed for the 2014 Special Olympics USA Games demonstrates the transportation feasibility for holding such mega events at dispersed locations in a highly populous and congested area under a tight budget. This is especially relevant because the transportation services were provided to individuals with intellectual disabilities who required high service levels.

## Conclusions

In this paper we discuss our development of a transportation system for Special Olympic Games, which strikes a balance between simplicity and effectiveness. Shuttle-bus service was the most costly and challenging component. To address it, we developed models and algorithms for (1) volume estimation for sightseeing demand, with minimum available data; (2) bus routing that is convenient, cost effective, and easy to understand; and (3) bus driver schedules that incorporate key features of both bus- and crew-scheduling problems.

Our experience with this project provided many valuable lessons. First, the key challenge to make a real-life impact was not only the model and algorithm development, but also the implementation, specifically, striking a balance between effectiveness and simplicity. Second, one-time mega events allow no errors during the event; thus, one must plan ahead for any unexpected issues. For example, our hourly volume estimation missed the peak demand because of unexpected changes in the participants' travel habits. Fortunately, we reserved a buffer of buses, which could be quickly put into service. Third, necessary information was not always available at the start of the project, and an iterative process of frequent interactions with customers was necessary. Finally, the game and special event schedule heavily affected the efficiency of the transportation system. Thus, one of our planned future studies on such mega events is to jointly optimize the event schedule and transportation systems.

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## Appendix A: Weighted-Average Travel Time

### Travel Time

Given the travel time between venue $i$ and $j$, $t_{ij}$, the weighted-average traveling time is

$$\frac{\sum_{(m,n)}(V_{mn} \times \sum_{(i,j)} t_{ij} y_{ij}^{mn})}{\sum_{(m,n)} V_{mn}},$$

where $(m, n)$ refers to a pair of origins and destinations, $y_{ij}^{mn}$ indicates whether $(i, j)$ is on the shortest path from $m$ to $n$ (depending on the routes of the shuttle-bus system), and $\sum_{(i,j)} t_{ij} y_{ij}^{mn}$ is the shortest time to travel from venue $m$ to $n$. If a bus switch occurs on the shortest path, a time penalty is incurred to represent inconvenience.

## Appendix B: Transportation Models

### Volume Estimation Models

*Assumptions*

- Everyone visits at most one other venue for sightseeing before returning to the hubs.
- Between venues $i$ and $j$, the volume (of sightseeing) from $i$ to $j$ is proportional to attendance in $i$ and attendance in $j$.
- The fraction of participants who would travel between venues for sightseeing is $\alpha = 25\%$. The fraction of participants living at hub 0 (1) is $\lambda_0 = 50\%$ ($\lambda_1 = 50\%$), respectively.

*Formulation*: *Parameter and indices*:

$A_i$ Attendance at each venue, $i = 0, 1, \ldots, 9$.
$S_{ij}$ Sightseeing volume from $i$ to $j$ ($S_{ij}$).
$H_{ij}$ Hub-returning volume without sightseeing from $i$ to $j$ (where $j$ is a hub).
$R_{ij}$ Hub-returning volume to $j$ (a hub) after sightseeing at $i$.

Given origin venue $i$, we discuss two scenarios about the destination venue $j$:

- *Case* 1: Venue $j$ is not a hub; sightseeing volume occurs only from $i$ to $j$ where $S_{ij} = \alpha A_i \times (A_j / \sum_{k \neq i} A_k)$ Thus, the travel volume between $i$ and $j$ is $V_{ij} = S_{ij}$.
- *Case* 2: Venue $j$ is a hub; sightseeing volume occurs from $i$ to $j$, $S_{ij}$; hub-returning volume from $i$ without sightseeing, $H_{ij} = \lambda_j (1-\alpha) A_i$; and hub-returning volume after sightseeing at venue $i$, $R_{ij} = \lambda_j \sum_k S_{ki}$. Thus, the travel volume between $i$ and $j$ is $V_{ij} = S_{ij} + H_{ij} + R_{ij}$.

**Bus Routing: Genetic Algorithm (GA)**

The algorithm, SO2014 GA, includes five iterations: initiation, evaluation, condition check, crossover, and mutation (Figure B.1). We defined the sequence in five steps with the fifth step returning to Step 2. The CONDITION defined in the program was the number of iterations. Once the number of iterations was reached, the CONDITION was met. In computation, we assumed that each stop takes a maximum of five minutes and each switch between loops cost 20 minutes. We obtained the hourly volume by evenly spreading out the daily volume to the periods available.

Our numerical study showed that enumeration was not computationally feasible for two or more loops. Too many combinations were generated, and the computation times needed to arrive at an optimal solution proved to be unrealistic and would not be transferable to future events. For such options, we used SO2014 GA. We carried out all numerical tests on an Intel Core-i7 CPU, 3.5 GHz (8 core) desktop workstation with 16 MB of memory. The algorithms were coded in Python and run using the Gurobi optimization program.

**Bus Driver Scheduling Models**

*Model Formulations*: *Model Development for Phases 2 and 3*

This model considers time windows for buses. We expect that a venue will have bus arrivals every 15 minutes. From 10:00AM to 6:00PM, we divide the time frame into 32 sections: 10:00–10:15AM, 10:15–10:30AM, ..., 5:45–6:00PM. For example, suppose the time horizon begins at 10:00AM (so that the first bus will be able to drive 30 minutes to arrive at the farthest venue). We convert 10:00 to $A_0 = 60$; 10:15 to $A_1 = 75$, and so on. In general, $A_k = 60 + 15 \cdot k$, $k = 0, 1, \ldots, 32$.

We hope a bus would serve only one venue during a day to reduce the risk. By this assumption, the problem can be decomposed into a set of subproblems, with each subproblem considering the bus-scheduling problem for one venue only.

*Parameters*:

$C$: Capacity of a bus.
$V_k$: Volume at cycle $k$.
$A_k$: Arrival time of cycle $k$.
$T$: One-way travel time from hub to venue.

Cycle duration: 15 minutes

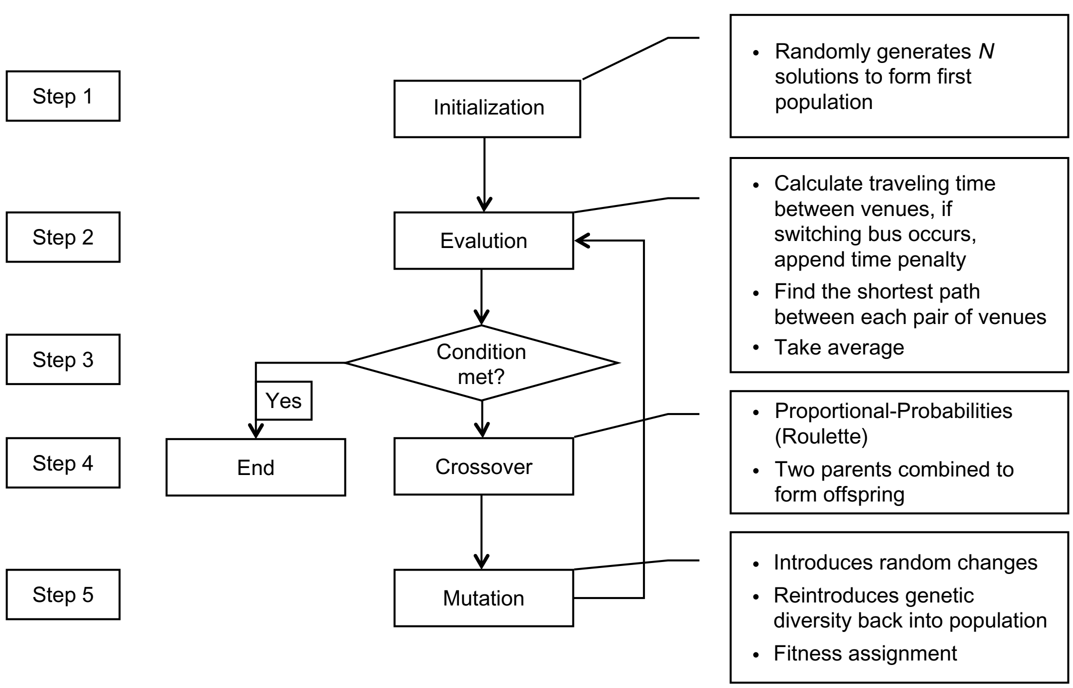


**Figure B.1: This flowchart of our SO2014 genetic algorithm shows its five iterative steps.**

*Variables*:

$x_k^b$: Binary, when =1, bus $b$ will satisfy the demand of the $k$th cycle.
$y^b$: Binary, when =1, bus $b$ is used.
$u^b$: Integer, the last cycle to satisfy.
$l^b$: Integer, the first cycle to satisfy.
$h^b$: Integer, reservation length for bus $b$ (hours).

*Objective Function*:

$$\min \sum_b h^b \tag{B1}$$

*Constraints*:

The volume at each cycle must be satisfied (capacity constraint):

$$C \sum_b x_h^b \geq V_k \quad \text{for all } k \tag{B2}$$

1. If bus $b$ visits venue at $A_k$ (cycle $k$), the time frame should satisfy (nonoverlapping task constraint):

$$x_k^b(A_k - 2T) + M \cdot (1 - x_k^b) \geq x_i^b A_i \quad \text{for all } i \leq k-1 \tag{B3}$$

2. Relationship between $x_k^b$ and $y^b$ (big-M for bus):

$$\sum_k x_k^b \leq M \cdot y^b \quad \text{for all } b \tag{B4}$$

3. A bus, if reserved, must be reserved for at least four hours (minimum-time requirement)

$$u^b - l^b + M(1 - y^b) + 2T \geq 4 \cdot 60 \quad \text{for all } b \tag{B5}$$

4. Relationship among $u^b$, $l^b$, and $h^b$ (starting and ending time constraints):

$$u^b \text{ and } l^b \tag{B6}$$

$$l^b \geq x_k^b A_k \quad \text{for all } k \tag{B7}$$

$$l^b \leq x_k^b A_k + (1 - y^b)M + (1 - x_k^b)M \quad \text{for all } k \tag{B8}$$

$$u^b \geq l^b \tag{B9}$$

$$u^b - l^b + 2T \leq 60 \cdot h^b + M(1 - y^b). \tag{B10}$$

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## Verification Letter

Lillian Narvaez, Chief Operating Officer, 2014 USA Games, 64 Walt Whitman Way, Hamilton, New Jersey 08690, writes:

"In June 2014, the Special Olympics USA Games was hosted by the state of New Jersey. 3,300 athletes with intellectual disabilities and 1,000 coaches competed in 16 sports across 10 locations and over 70,000 spectators were in attendance. As with any sporting mega-event of this magnitude, transportation was among the top dominant factors in realizing success. Efficient bus routes and schedules were needed to

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ensure timeliness and convenience between 10 venues, three airports, and five special event locations while remaining under the transportation budget of $600 K.

"We solved this transportation problem using a three-phase approach. Phase 1 optimizes the number of shuttle-loops and buses required to efficiently transport athletes and coaches to competition venues using the enumeration method. We then developed a time matrix and volume estimation models to ensure the transportation network was equal to or under the budget. During this phase, we also designed a genetic algorithm enabling us to find the sub-optimal solution faster than by enumeration alone. Phase 2 sees the integration of the athletes proposed travel habits and a more focused volume estimation model detailed in hourly variations instead of a daily volume total. Finally, Phase 3 solves the shuttle-bus problem by a more direct approach. Due to the constrained competition and special event schedules, we needed a direct route to and from each hub and non-hub venue to ensure all timelines were met.

"With the experience of the Academy Bus Company operation managers, we evaluated this three-phase methodology by applying to a real-world mega-event (the 2014 Special Olympics USA Games) resulting in a huge success. Even though this event did not result in substantial transportation savings, we were however, able to streamline the process ensuring athletes with intellectual disabilities and their coaches were able to make every competition with zero delays."

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**Andrew Johnson** is a professor in the Department of Marketing and Business Information Systems at Rowan University. He holds a PhD in supply chain management and marketing sciences from Rutgers University. His general interest lies in supply chain management and logistical systems with special focus on transportation planning, inventory control, military applications, and the integration of supply chain management with project management. He teaches supply chain logistics management, business logistics, global supply chain management, principles in transportation, and research methods in marketing for undergraduate and MBA programs at Rowan University. He is a 20-year veteran of the United States Air Force, retiring in 2007.

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