Managing Large Flows In Metro Stations:
Lessons Learned From The New Year Celebration In Copacabana

Mario Campanella 1, Rafael Halliday 2, Serge Hoogendoorn 1 and Winnie Daamen 1

Abstract—Around 2 million visitors reach the beach of Copacabana in Rio de Janeiro on the New Years Eve every year. More than 100.000 visitors travel by Metro and around 70% use the Cardeal Arcoverde Station (CAV) as their destination. This creates large pedestrian flows inside the station causing major discomfort and endangering the station users. With the steady increase of the flows in recent years a system engineering approach is applied to mitigate the circulation problems. The approach identified the station (and its components) as an open system with a feedback mechanism (crowd management measures). The system itself is connected to other systems such as the station surroundings and the trains. A system analysis, determined the individual capacities of the station components, their dynamic properties, mutual influences and dependency to the other systems. Based on these, crowd-management measures were devised and enforced in a contingency plan that improved the safety and comfort of passengers during the 2012-2013 event. The bottlenecks were better understood and their capacity improved causing significant less crowding in the station and allowing a rapid action of marshals when an emergency occurred. We conclude by showing the improved results that a system engineering approach is a useful approach to plan and access large crowds events.

I. INTRODUCTION

In many a metropolis a significant amount of people commute using public transport creating intense pedestrian flows in daily peaks. Music shows, sport events and other festivities also create concentrated crowds that can expose people to dangerous situations. The knowledge of pedestrian behaviour in crowds is comprehensive and has been successfully applied to manage large crowds [4]. However, recent events showed the tragic consequence of poor planning and management of crowds [5] [6].

Crowded situations are also found in car traffic. When densities get too high, shock waves, spill-back and congestion may occur decreasing the efficiency (flow of vehicles/time) and causing delays. During the past decades, effective Intelligent Transport Systems (ITS) were devised and applied to minimise or prevent these negative effects into traffic [7]. Real-time information, speed-control, forced route change and the green wave have proven to be effective. Similarly to car traffic, pedestrian traffic properties are also described in terms of speed, flow and densities indicating that even if there are differences between them, pedestrian traffic management can profit from the practice of ITS measures [7].

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When moving in crowds pedestrians behave strongly in reaction to the surrounding conditions. Fruin [8] introduced the notion of Level of Service applied to pedestrians. The six levels of LOS are a powerful indicator of the effects of the traffic characteristics (density, speed and flow) to the behaviour of individual pedestrians. In lower levels of LOS (A, B and C) pedestrians walk generally more free and move without much hindrance. Level D is the level in which movement is somewhat restricted but the flow is still fluid. At LOS E practically all pedestrians are restricted in their normal speeds and the flow is the maximum (capacity). LOS F is a condition that must be avoided because pedestrians are too close and the condition is not safe.

The primary goals in the design and in the operation of walking facilities is to give pedestrians the opportunity to safely and comfortably move from their entry to their exit points. This becomes a challenge when the inflow is much larger than the outflow. In these cases congestion can build up and the LOS deteriorates to dangerous values [9]. Ideally the design of the walking facility is such that it can accommodate safely the extra pedestrians until the unbalance is restored. For this to happen, the facility must have some alternative space and the pedestrian flows must be directed to these spaces. Often this is not a simple crowd-management operation because of the complexity of the situation.

A walking facility can be described as a connected system comprising of a set of activity areas reached via walking areas [10]. Activity areas are places where pedestrians (usually) stop before resuming their journey. Passing turnstiles, looking to information boards, waiting for a metro are examples of activities that usually are performed in metro stations. Corridors, platforms, staircases and escalators are places where pedestrians walk (or wait). These areas are usually connected in such a way that critical situations have a decisive influence on other areas. Congestion can spill-back, areas with high density blocking the flows may induce pedestrians to re-route and start congesting other walking areas, busy trains with no room for passengers will cause platforms to increase occupancy. From these few examples it becomes clear that the influence between parts of a walking facility must be accounted for and must be well understood. Quoting Ludwig von Bertalanffy the initiator of the General Systems Theory we emphasise the need of system thinking into crowd-management:

It is necessary to study not only parts and processes (of systems) in isolation, but also to solve the decisive problems found in the organization and order unifying them, resulting from dynamic interaction of parts, and making the behaviour...
of parts different when studied in isolation or within the whole [2].

This paper proposes the use of concepts of system engineering to manage the complexity of crowd-management. Basic principles of feedback systems are used to create a series of crowd-planning and crowd-management actions that were designed to be applied in the 2012-2013 new year celebration in the Copacabana beach in Rio de Janeiro Brazil. The actions are described and their effects in the station flows presented. The actions proposed had beneficial effects because they were well designed and because of a high compliance of the pedestrians in the crowds, even in intense flows. This has important implications to crowd-management in general by showing that favourable external conditions are determinist for safe flows.

II. SYSTEM ENGINEERING APPROACH OF METRO STATIONS

Walking facilities such as metro stations are dynamic systems since pedestrian traffic evolves with time independently of changes in the boundary conditions (in and outflows). Also metro stations are open systems with several entrances and exits that connect them to other neighbouring systems such as metro stations, train stations, bus stations and the city. If we look at metro stations operations from a pedestrian flow perspective then the crowd-management is the feedback mechanism that keep pedestrians in safe and (as much as possible) also in comfortable states.

A well designed feedback system does not behave as an unstable system. Such systems may present conditions that cause flows, speed and densities not to converge to a stable and safe state. For instance Helbing [2] shows how under extreme conditions crowds behave like turbulent flows. In these conditions pedestrian flows disappear and pedestrians move without control in unpredictable directions. This is extremely dangerous and Helbing appoints the extreme pressure in turbulent flows as the cause of causalities in the massive crowd event in Mina/Makkah during the Hajj in 1426H on January 12, 2006.

There are many indicators possible to trigger the feedback mechanisms. For instance the pedestrian traffic characteristics can be measured (or estimated) and applied with a threshold value (e.g. when the LOS in the platform reaches level E). There are several control mechanisms available such as reducing the inflows by by-passing trains or redirecting flows towards non used parts of the station.

III. PLANNING THE NEW YEAR CELEBRATION WITH SYSTEM ANALYSIS

The contingency plan described in the following sections was created using operational data and observations realised during the new year operations in the year 2011-2012. The operational data used included inflows and train operations. The observations gave an overview of the crowd-management capabilities, exceptional conditions that can happen during the event and to assess the influence of important aspects of the station infrastructure.

The station Cardeal Arcoverde (CAV) is not subject to intense flows during normal operations but during the celebrations of the 31st of January the normal inflow of 12,000 users/day jumps to 70,000 users/day (Fig. 1). This amount of users puts a lot of stress into the operation of this moderate sized station and created the need of a special events contingency plan.

A. Analysis of the station

The CAV station is a very long station with only one possible route between the platform and the exit. The station has four levels, the platform, two intermediate levels that are long corridors and the street level with one row of turnstiles and two exits. The total walking distance is approximately 250m without the platform. Each level is connected by a set of escalators and staircases. The platform level is composed of two lateral platforms divided by the rails. The second level corridor initiates as a footbridge overlooking the platform. The footbridge receives pedestrians from the escalators and stairs and is the narrowest part of all corridors with 3.85m width. It has low handrails that could potentially be dangerous in a overcrowded situation.

Measurements showed that visitors want to arrive in the beach one hour before the 24:00. The peak in the station is between 22:00 and 23:00. This caused overcrowding into the CAV station and in some of the origin stations. The trains also were very full and the surroundings of the stations also tend to get very crowded. The new year transport operation offers a limited amount of tickets for sale. Users of the system can buy tickets that are valid only in one hour slots. With this a upper limit of users is set.

The return after the celebration does not present the same problems. Many users start the return immediately after the celebrations and other stay longer enjoying the shows and events that occur in stages set on the beach. Furthermore, many pedestrians also use neighbouring stations as the origin of their back journey. Therefore, the crowd-management analysis only focused on the circulation of arriving pedestrians before 24:00. Tab. I shows the amount of users arriving
between 19:00 and 24:00 and departing between 24:00 and 5:00 from the CAV station. It also shows the tendency of growth in the last couple of years.

| TABLE I |
|---|---|---|
| METRO USERS ARRIVING AT AND DEPARTING FROM CAV STATION DURING THE SPECIAL NEW YEAR OPERATION. |
| 2011-2012 | 2012-2013 | increase |
| arriving | 65,535 | 68,735 | 5 % |
| departing | 55,924 | 69,196 | 24 % |

This event has some peculiarities that makes it different to more common mass gatherings such as music shows and football matches. Below we summarize the description of the pedestrian population and their behaviours:

- The general mood is of celebration and the people are very cheery up on arrival. (medium walking speeds)
- Pedestrians are very tired at departure (slow walking speeds).
- Many people carry big bags and boxes with food, drinks and personal items. (moving bottlenecks)
- Very heterogeneous population with people of all ages (necessity of overtaking).
- Strong group behaviour: couples and families. (many stops)

1) Type of flows: The topology of the station is very simple and only bidirectional flows are possible. In the previous years during the new years event the flows were very unequal with large flows from the platforms to the upper levels and small opposite flows.

2) Connectivity of the walking areas: Given the linear topology and the absence of intersecting flows, a simulation study is not necessary. A static analysis of the circulation is sufficient to determine the bottlenecks and the station capacity.

3) Bottlenecks and Station Capacity: In this section we assess the capacities of each component of the station. For each level we determine the capacity by choosing the component with smallest capacity. The component with the lowest capacity determines the station capacity. The components capacities are calculated using the following base values:

- Escalators: Maximum theoretic of their double escalators is 8,000 peds/hour. Manufacturers recommend a factor of 0.8 for determining capacity. (1.8 peds/escalator/s).
- Stairs: Capacity according to the Highway Capacity Manual is 49 peds/m/m [?] . (0.82 peds/m/s).
- Turnstiles: Average measured service time while exiting is 1s. (1.0 peds/m/s).
- corridors and doors: Capacity according to the Highway Capacity Manual is 75 peds/m/m [?]. (1.25 peds/m/s).

According to [?], capacity for corridors, doors and stairs occur for LOS E. That is a condition not recommended for normal use but acceptable for evacuations and will be used in the following calculations.

For the sake of brevity the station geometry is not presented. The base values are multiplied by the components dimensions, quantities and the results are presented in the Tab. II.

<p>| TABLE II |
|---|---|---|
| THE FLOWS IN peds/s FOR EACH CRITICAL COMPONENT AND LEVEL. |
| THE BOLD VALUE (LEVEL I) IS THE STATION CAPACITY. |</p>
<table>
<thead>
<tr>
<th>level</th>
<th>component</th>
<th>capacities (peds/s)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>components</td>
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<tr>
<td>platform</td>
<td>stairs</td>
<td>(2.9)</td>
</tr>
<tr>
<td></td>
<td>escalators</td>
<td>(3.6)</td>
</tr>
<tr>
<td>corridor 1</td>
<td>stairs</td>
<td>(2.4)</td>
</tr>
<tr>
<td></td>
<td>escalators</td>
<td>(3.6)</td>
</tr>
<tr>
<td>footbridge</td>
<td></td>
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<tr>
<td>corridor 2</td>
<td>stairs</td>
<td>(2.4)</td>
</tr>
<tr>
<td></td>
<td>escalators</td>
<td>(3.6)</td>
</tr>
<tr>
<td>exit</td>
<td>main access</td>
<td>(8.5)</td>
</tr>
<tr>
<td></td>
<td>sec access</td>
<td>(5.0)</td>
</tr>
<tr>
<td></td>
<td>turnstiles</td>
<td></td>
</tr>
</tbody>
</table>

The maximum flow that can pass in one hour by the footbridge is \( k_{max} = 4.8 \times 3,600 = 17,325 \) peds/hour. If we multiply this number by the five hours of the special operation we obtain the maximum theoretic arrival of pedestrians that can pass the station during this period is \( A_{max} = 86,625 \) peds. This value was chosen as the upper limit of tickets sold during the operation. This number is 21% higher than the arrivals in 2012-2013 (see Tab. I) indicating that one in five tickets sold are not used.

By examining the distribution of the inflow per hour measured at the departure stations we determined that during the peak hour between 22:00 and 23:00 the station is operating in capacity. The other hours operate between LOS D and LOS E (Tab. III). These high level of LOS during the event and specially during the peak hour supported the need of a contingency plan. In the following sections the peak hour will be used for the identification of actions part of the contingency plan.

| TABLE III |
|---|---|---|---|---|---|---|---|
| THE LOS VALUES TAKEN FROM [?]. |
| density (peds/m²) |
| LOS A | LOS B | LOS C | LOS D | LOS E | LOS F |
| wait | < 0.8 | 1.1 | 1.7 | 5.3 | 5.0 | > 5.0 |
| walk | < 0.2 | 0.3 | 0.5 | 0.7 | 1.3 | > 1.3 |

B. Planning actions

In this section we present the most important measures taken after the observation and analysis of the operation in the previous years. In normal conditions (no incident happened) the largest attention goes to the flow in the footbridge (the station bottleneck). Its deep position in the station and the direct connection to the platform is not favourable. The congestion formed in its entrance spills-back towards the platform slowing the evacuation of the platform. Given that escalators do not spill-back the risk of
overcrowding the area between the exit of the escalators, stairs and the footbridge is significant. Most planning actions aimed to improve the flows in and out of the footbridge to make sure that the platforms were evacuated as fast as possible.

1) Increasing the capacity of the footbridge: Observations of the flow in the entrance of the footbridge showed that the left curve of 90° that pedestrians need to take after leaving the escalators and the stairs decrease the capacity of the footbridge. Pedestrians tend to approach the curve from the inside part instead of the outside thus reducing the distance walked (also referred as curve hugging effect). This causes a funnelling that increases the density in the inner parts of the curve causing discomfort, unsafe conditions and decreases the capacity of the footbridge. This was addressed by cutting an angle into the concrete obstacle on the sides of the staircases that connect the platform with the first level. These cuts allowed for soft changes in flow directions between the outflow of the escalators and stairs and the inflow of the footbridge.

2) Bidirectional flows: During the previous events users could also enter the CAV station and board trains that were going further. These users where in very small numbers and had huge difficulties in reaching the platform and disrupted the main exiting flow. The main problem when walking in small numbers against a large stream is the impossibility to self-organise lanes. Each pedestrian must fight his or her way against many opposing pedestrians and they require more space than the conditions require \cite{[7]}. The formation of lanes is very dependent of the proportion of the flow and \cite{[7]} indicates a 13% of capacity loss for very unequal bidirectional flows (90%/10%). The consequence was that during some moments the capacity of the footbridge would drop to 4.2 peds/s. Therefore, it was determined that no boarding of passengers was allowed in the CAV station during the special operation. This required a large information campaign prior to the event to avoid discontent.

3) Evacuation of causalities: During the operation it occurs that people faint, feel unwell or have respiration problems inside the station. The station staff is prepared to assist in minor cases and they are instructed to carry the needed to a first-care room in the exit level for reanimation and assessment. Experience showed that many of the cases occur during the train journey and on the footbridge. The usual behaviour is for passengers to be carried to the attention of one of the staff members that will call for help. The journey from the platform to the exit in LOS E conditions takes 8.0 minutes (6.0 minutes for LOS D). The delay will be more than double these values if the assistance needs to come from the exit level (see Sec. III-B.2). This motivated the installation of a lateral corridor of 1.0 meter width in the side of the corridors 1 and 2 to allow for fast evacuations. The main corridors have a width of 11 meters, taking one meter does not affect the evacuation capacity. The expectation is that the walking time could be diminished in at least 1.5 minutes and be significantly more comfortable.

4) Increasing the number of marshals: One of the most important aspects noted in previous years, was the overload of the marshals. The fluctuations during the normal operations were too large due to insufficient intervention by the marshals. For the 2012-2013 there was a 100 % increase in the number of marshals increasing from 15 to 30 for the whole station. Also they got more training and briefings. The marshals were asked to present firm but friendly attitudes and not to demonstrate stress or ruthless in their behaviour.

5) Review of information systems: The communication system through visual and auditive signs was also improved. Extra signs indicating the secondary exit were temporarily put in place and the loudspeaker system revised and improved.

6) Train headway planning: The train capacity is 1726 pedestrians. 62% or 1070 is the maximum amount of pedestrians that alight the train in the CAV station. In the peak hour it would take 1070/4.8/60 = 3:40 minutes to evacuate the platform. Given that the useful platform area is 550m² and can receive 1833 pedestrians in LOS D (see Tab. III). The smallest headway in the peak hour with a minimum margin of safety is 4.0 minutes. This value was adopted in the planning predicting that the platforms would be always empty in normal operations. Therefore the boarding and alighting process should only occur with empty platforms.

C. Crowd-management actions

In this work we define two levels of crowd-management actions, one for normal situations and another for exceptions during the operation. Normal situations are those that occur when all components of the metro system are functioning and the pedestrians stay walking with speeds corresponding to A until D LOS conditions. Deviations of the normal conditions due to natural fluctuations in the behaviour of pedestrians or from the metro systems should not require any change in the status of the crowd-management. This is the equivalent of a stable state from a dynamic system.

Exceptional actions are required when something caused an extreme disruption of the pedestrian flows for a long enough period (LOS E or F). In these cases the normal actions are not enough to restore the flow levels. Exceptional actions are more important than normal actions because of the quick deterioration of the safety. During normal operations pedestrians walk with a level of comfort and due to the higher walking speeds stay less time in the station. When a flow disruption occur, congestion builds up quick and pedestrians stay trapped inside the long station. Therefore, actions to mitigate or solve the exception are most important.

Anticipating all possible exceptions is very difficult. Previous experience helped to identify two dangerous exceptions that occurred with some frequency, rain and the stopping of escalators. However, there are potentially many other aspects of the operation that can cause congestion.

The not anticipated exceptions are the ones that give the most concerns given that no dedicated action can be planned. Therefore we devised a simple way to control the inflow in the station to limit the crowding for extreme situations. The
action is a train headway management indicator assessed by the station marshals to prevent the spill-back of the flow to reach the platform.

These four crowd-management actions are included in the contingency plan and are detailed in the next sections.

1) Normal situation actions: The most important normal crowd-management actions are, dispersing pedestrians near the exits, directing users to the secondary exit, dispersing pedestrians near the turnstiles waiting for members of their groups, monitoring the flows in the lower levels (specially in the footbridge), helping the alighting of slow pedestrians and assisting in cases of causalities.

2) Congestion in the exit level (rain): When it rains, the capacity of the doors at the exit level drops significantly. Pedestrians tend to practically stop to take extra actions such as opening umbrellas before leaving the station. The areas before and after the turnstiles in the exit level can receive 550 standing pedestrians in LOS D or 820 in LOS E. The congestion then spills back to the lower levels requiring intervention of marshals.

When rain starts, immediately more marshals are positioned near the doors. Furthermore, more police agents are asked to help dispersing the stopped pedestrians. The area before the turnstiles can only accommodate 43 pedestrians walking in LOS E. If its occupation increases too much, marshals will act very actively dispersing the blockage. The urgency of the dispersal depends where the bottleneck is occurring. If the problems are around the turnstiles an effective action of marshals improve the situation quick. If the congestion is outside the station than more time is needed to re-establish the proper outflow. Therefore the marshals are instructed to anticipate blockages outside the station.

In extreme cases the marshals can stop and block one or two of the escalators that connect the second level preventing crushing before the turnstiles. The decision of when to stop and the amount of escalators to block is left to the marshals as a last resort. Sec. III-C.3 and III-C.4 show the risk of stopping escalators.

3) Auto-stop of the escalators: The mechanical stress on the escalators that are not designed for the effort encountered during the special operation causes the auto-stop mechanism to activate frequently. After it occurs it takes a marshal to block the access to the escalator, wait until it is emptied and then restart it (this is a safety regulation). During this time the capacity of the station decreases substantially and spill-back will start on the corresponding level. When a escalator stops its capacity drops significantly from 1.8 peds/sec to 0.8 peds/sec (see Sec. III-A.3). This value decreases the combined capacities of escalators and staircases to values similar of the footbridge. The escalators mostly affected by this problem were located between corridor 2 and the exit level. It was noticed that congestion build up very quick. The escalator is perceived as less comfortable and pedestrians start hesitating between the stopped escalator and the nearby staircase.

When this occur, marshals are sent directly to the base and the top of the escalator. The marshal in the top makes sure that pedestrians do not block the outflow of the stopped escalator. One marshal in the bottom blocks the escalator, another direct pedestrians to the other escalator and to the staircase. When the escalator is empty, the top marshal restarts it. If the escalator does not start immediately, then the marshals start monitoring the spill-back in the level. For level 2 the spill-back should not reach too close to the escalators and stairs from the level 1. For the level 1 the same applies for the critical length ahead of the footbridge as described in Sec. III-C.4. If there is no solution for the mechanical problem, marshals may consider stopping one escalator of the lower level to match the capacities and contain the spill-back.

4) Train headway management: During the special operation the inflow only comes from trains. Therefore, they must be stopped or have their speed reduced until acute congestion problems in the CAV station are solved. Increasing the headways is a critical action because it has to be realised without causing congestion to the other stations. Its application must be gradual. First, there must be an increase of headway by slowing trains. If this measure is not enough, trains will be stopped or diverted to the following station. The latter measure is very badly perceived by the users in the diverted train and should be avoided if possible. Past experience showed that verbal communication inside the trains was not effective and users got very upset of having to alight in a different station.

To apply the train headway management, one has to be able to access the crowding in the station, evaluate one or more indicators and coordinate with the control centre. All this must be done during the operation in less than optimal conditions. Therefore, the primary condition for the effective use of the headway action is the choice of a simple and easily accessible indicator. This indicator determines when to start and when to finish this action.

The indicator chosen is the length of the spill-back in the first level. One or more marshals positioned in the first level keep track of the length and speed of the spill-back. They will notify the control centre to slow down trains when the spill-back reaches a critical length (C_l). This critical length is such that the space left in the corridor of the level 1 in LOS E can receive a whole train with no pedestrian in the footbridge. A calculation using full train capacity (1756 users) gives a \( C_l = 32 \) meters from the footbridge.

If after the arrival of the slowed train the spill-back crosses the critical length then the marshals will ask the control centre to stop the trains. The decision to stop the train or to by-pass the station will be taken by the managers of the control centre according to the position of the next train and the crowding of the upstream stations.

IV. RESULTS AND CONCLUSIONS

A. Results for the 2012-2013 event

Despite a 5% growth in arriving users (Tab. I) less incidents of overcrowding were observed in the 2012-2013 new year special operation. In general the perception of all involved in the operation was that there was less stressful
moments and in general the whole operation was more safe. Unfortunately, there is no data comparing quantitatively the two events in terms of crowding. However, situations with LOS E were much less frequent in the second event and the spill-back never reached the footbridge as in the previous year when at one moment the platform was not empty when a train arrived causing extreme crowding. Below is summarised the results for some of the actions implemented.

- The effect of the modification of the entrance of the footbridge was significant (Sec. III-B.1). Much less pedestrians were crushed and the flow was much more smooth in the area between the platform staircases and the footbridge.
- The decision to create a dedicated corridor to allow for a quick evacuation of casualties proved to be very effective (Sec. III-B.3). The time needed for marshals to walk against the flow diminished substantially and the evacuations occurred with much more comfort. The corridors were formed by crowd control posts and barricade tapes were respected and the lateral corridor was very much respected and not invaded.
- More pedestrians took the secondary exit because of better communication (Sec. III-B.5).
- The good intervention work by the marshals prevented overcrowding in the exit level (Sec. III-C.2).
- The train headway varied substantially due to overcrowding of the origin stations. The control centre had less freedom to enact headway management action (Sec. III-C.4) due to intense occupation of the origin stations. However, their judgement was very much aided by the information about the length of the spill-back in the corridor 1. Their intervention proved effective and the platforms never contained pedestrians when trains arrived.

B. Findings

The experience of observing, analysing and applying management actions over two similar events enable us to generalise some of the conclusions into findings that should be applicable to other similar situations. A general finding that may however vary according to cultural differences is a large tolerance for high densities. During the moments in which the perception by the pedestrians was of normality and that the situation was under effective control they would continue walking according to the crowd-management actions. This happens even within intense flows. The following findings are more general and should be applied whenever large pedestrians flows and crowding are expected:

- The visual communication was more effective than the verbal announcements. Even after the improvement, the noise generated by the pedestrians diminished the efficiency of the loudspeakers. When pedestrians saw that the main exit was very congested they would then put their attention to the (well positioned) signs pointing to the secondary exit.
- Improving the efficiency of pedestrian flows requires the removal of all obstacles that can disrupt the flows. Sharp corners, signs, bins should be removed or relocated to areas of low flows.
- Bidirectional flows should be avoided and separation between opposing directions should be installed.
- Marshals should follow simple and effective rules to guide their actions. Good coordination between the different people involved in the crowd-management contributed for the good outcome of the event.

C. Conclusion

A proper analysis of the crowding event is fundamental for its success in terms of safety and public satisfaction. This paper presents an approach inspired on system engineering to plan and manage a crowded venue as a connected feedback system. This analysis lead to the identification of planning and crowd-management actions. Some actions are proposed and successfully tested in a real event. The result of the system approach is a contingency plan that improved the safety and comfort of visitors of new year special operation of the MetrôRio.

The next step is to extend the approach into a proper system analysis framework. This will allow for more robust contingency plans to be created for complex situations with non-linear effects due to complex topology of the walking areas and pedestrians behaviours.

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REFERENCES