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Zone Zn_z has p_z stretches of set J which only belong to Zn_z and do not belong to any other zone of the manoeuvring area. Therefore:

$Zn_1 \cup Zn_2 \cup \ldots \cup Zn_z \cup \ldots \cup Zn_h = Zn' = J \qquad Zn_i \cap Zn_j = \varnothing$ con $i,j \in (1,2,\ldots,z,\ldots,w)$

Each zone starts in stretch 1 and ends in any of the stretches that share a common vertex with stretch 1 of the next zone. This vertex is called Final Node and *endnode* is the subset of stretches that converge on the final node. The inequality which requires the snow-clearing process of a zone to end on some stretch of the subset *endnode* is as follows:

$$\sum_{i \in endnode} \sum_{j=1}^{n} x_{ij}^{k} = 1 \qquad i \in endnode \quad k = m \tag{5.15}$$

Therefore, inequality (5.15) replaces inequality (1.12) in all zones except the last one, Zn_w, and is an operational restriction that establishes that the clearing of each zone must finish through one of the stretches contained in the subset of *endnode* stretches defined for each of the zones.

According to the results of the analysis, the recommended number of stretches in each zone should be between 30 and 40, and should not exceed 50.

The subsets of the target stretches must be completely contained in one of the zones into which the manoeuvring area is divided so that only the affected subset will be included in each partial solution. In other words, for any $J_i = (1, 2,\ldots, t,\ldots, q_i) \subset J$, with $i \in (1, 2,\ldots, z,\ldots, h)$, J_i belongs to a single zone Zn_j, with $j \in (1, 2,\ldots, z,\ldots, w)$.

The solution is achieved via successive iterations to approach the final solution. In each iteration the w zones are processed in the following order: Zone 1, Zone 2, ..., Zone z, ..., Zone w.

An outline of the process for arriving at a solution is given in Figure 1. It has the following data and variables:

Iteration data:

Each zone has common data, such as p_i, δ_{ij}, which is independent of the iteration of the process. The first zone starts with an origin time equal to 0 minutes. The next zone Zn_1starts with an origin time of el R_{max}^{Zn1}, the next zone Zn_2 has a time of R_{max}^{Zn2}, and so on so that in Zn_w, $R_{max}^{Znw}=R_{max}$ which is the entire manoeuvring area for the actual iteration of the process. The target data of each subset is adjusted with each iteration, thereby approximating the estimated times to the results of the previous iteration. So, for iteration I_n, the target datar_{total}, r_{RWY-Ai}, r_{RWY-Di}, $r_{ZDe-icek}$, r_{APR}, $r_{APR-ZDe-icek}$ adjust to the results of iteration I_{n-1} R_{RWY-Ai}, R_{RWY-Di}, $R_{ZDe-icek}$, R_{APR}, $R_{APR-ZDe-icek}$.

Iteration variables:

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For each zone the variables are s_i^k, R_i^k, p_i^k, x_{ij}^k y R_{max}, with the addition of $R_{max\ z}$ and l_z in the subsets of significant stretches within each zone. The value R_{max} of one zone is the origin of the times in the following zone, as explained in the paragraph above. The variables resulting from a given iteration In are $R_{RWY\text{-}Ai}$, $R_{RWY\text{-}Di}$, $R_{ZDe\text{-}icek}$, R_{APR}, $R_{APR\text{-}ZDe\text{-}icek}$ and $l_{RWY\text{-}Ai}$, $l_{RWY\text{-}Di}$, $l_{ZDe\text{-}icek}$, l_{APR} and $l_{APR\text{-}ZDe\text{-}icek}$, with the variables $R_{max}^{ZnwIn}=R_{max}^{In}$ and $l_{total}^{ZnwIn}=l_{total}^{In}$.

The process is finished when in iteration I_z the times are not better than those achieved in iteration I_{z-1}. The final result of iteration I_z for the variables is $R_{RWY\text{-}Ai}$, $R_{RWY\text{-}Di}$, $R_{ZDe\text{-}icek}$, R_{APR}, $R_{APR\text{-}ZDe\text{-}icek}$ and $l_{RWY\text{-}Ai}$, $l_{RWY\text{-}Di}$, $l_{ZDe\text{-}icek}$, l_{APR} y $l_{APR\text{-}ZDe\text{-}icek}$, with the variables $R_{max}^{ZnwIz}=R_{max}^{Iz}$ and $l_{total}^{ZnwIz}=l_{total}^{Iz}$.

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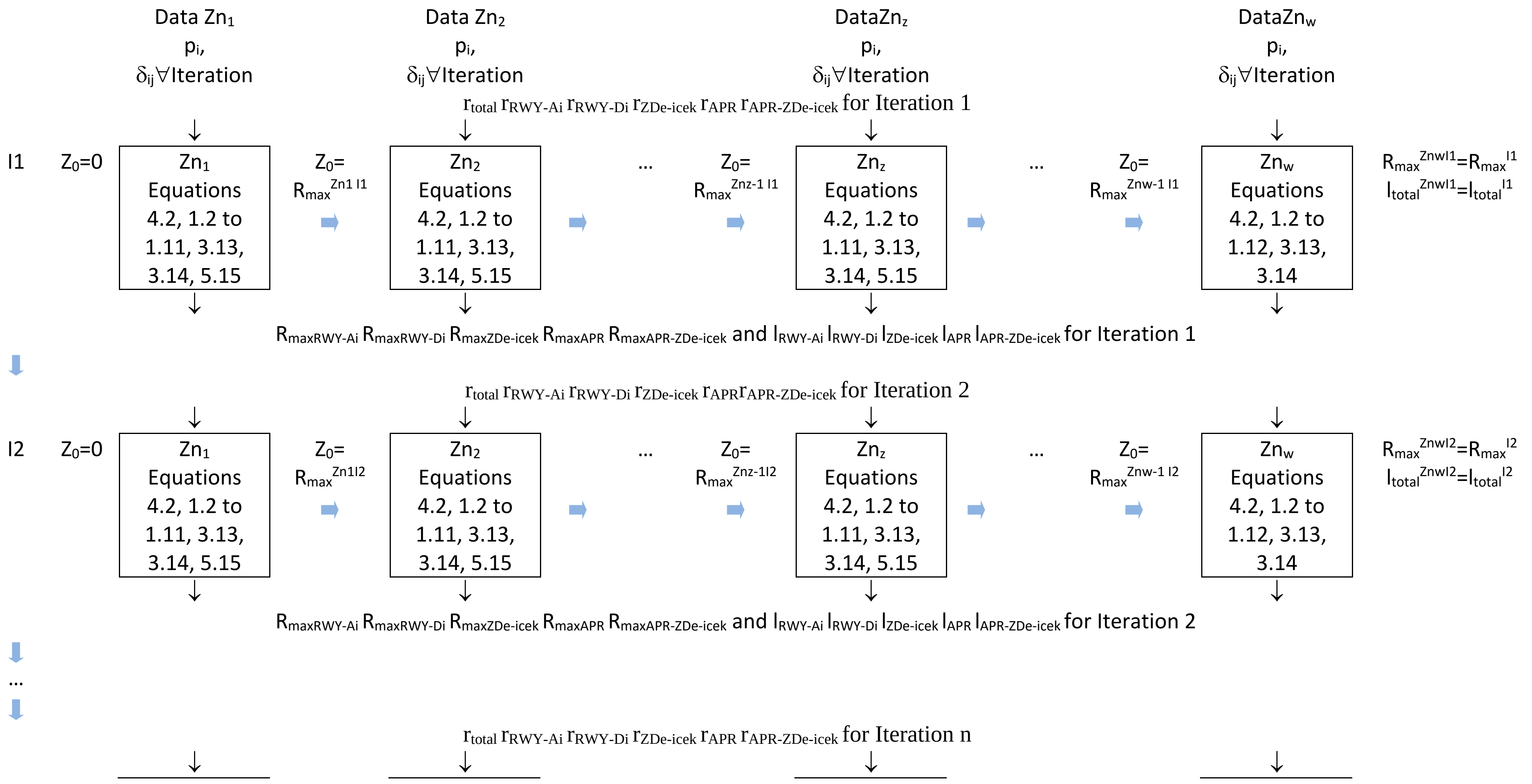

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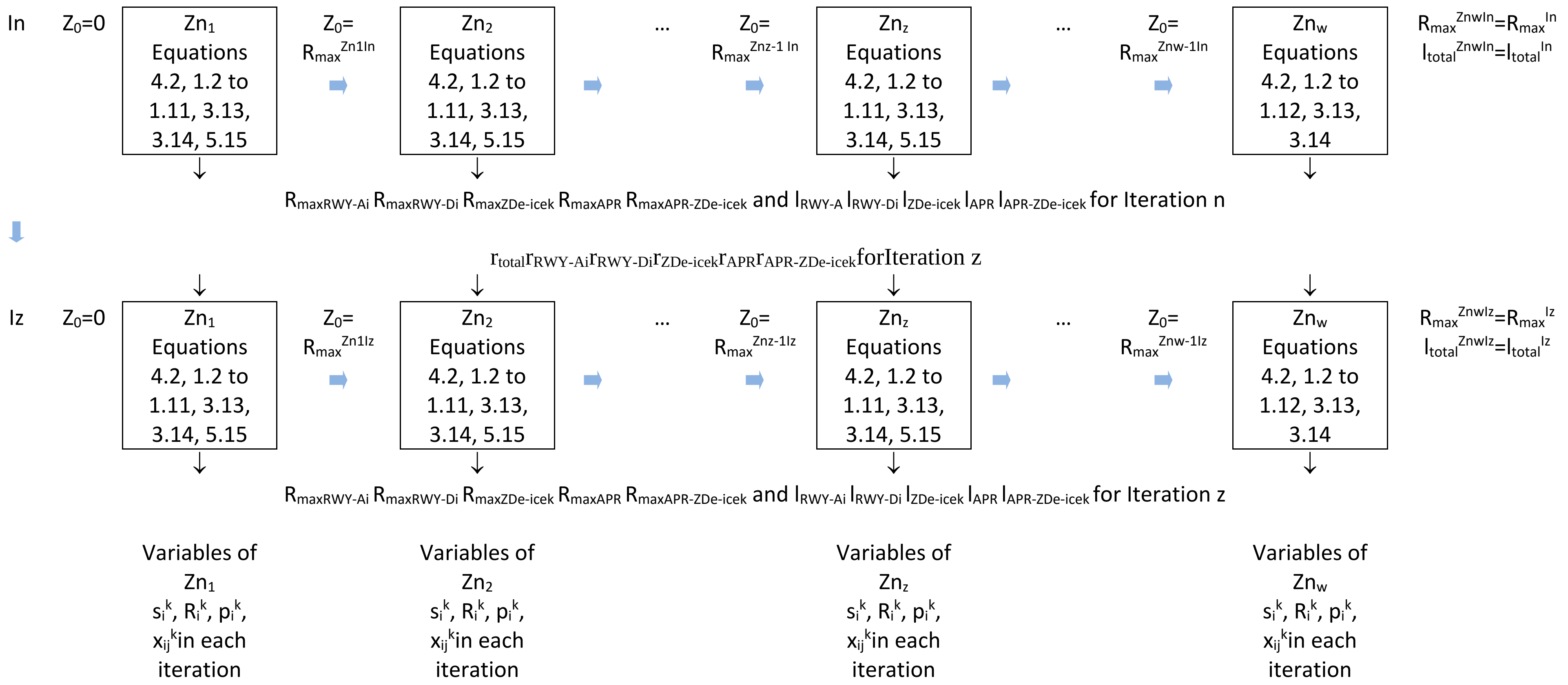

Figure1: Process for applying the proposed problem-solving method to the problem RM-MA using scheduling theory

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3. Case Study: Application of the model to manoeuvring area T4S of Adolfo Suárez Madrid-Barajas Airport.

3.1. Modelling the manoeuvring area.

We will consider a manoeuvring area at Adolfo Suarez Madrid-Barajas Airport, incorporating the apron area of terminal T4S and runways 14L-32R and 18L-36R in North configuration, in other words, with 32R for landings and 36R for take-offs. The manoeuvring area consists of an apron with stands, both remote and in front of the terminal building, and the two runways already mentioned used exclusively for take-offs and landings. We divided the axes of the taxiways and runways into stretches and each was assigned a consecutive number. The stretches are defined by the points of intersection with other stretches.

In total the model has 117 stretches (Figure 2). There are stretches in which snow can be cleared in just one pass and others, such as the runways, which require several passes and with different configurations of the machines. To calculate the performance of the machines we have considered the length of the stretch and have assumed that the snow-clearing machines operate at a speed of 40 km/h. The assumption is that all stretches undergo one pass except for the runway, which requires four. In each stretch the snow-clearing operation will be carried out at constant speed except at the beginning and the end of the stretch where the speed tends to decrease. This variation is considered to be negligible for the purposes of the theoretical calculation. The times suggested by the model were compared with those achieved in live simulations to validate the performance. In the event of a snow-clearing machine operating at a different speed, the performance will be adapted.

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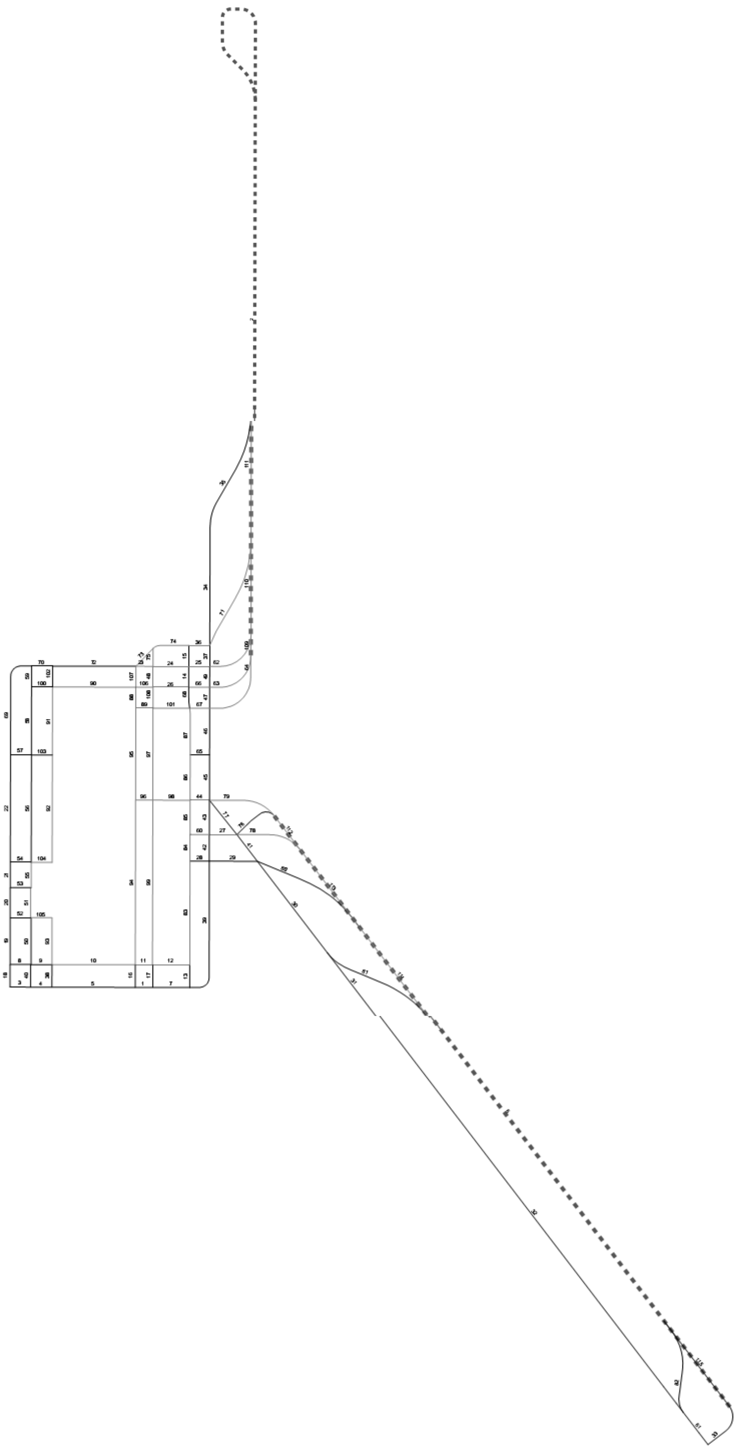

No. of stretches: 117
Length: 36,289 m

Figure2: Configuration of the manoeuvring area T4S used for the computational tests

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3.2. Particularisation of the problem-solving methodology

Bearing in mind the conclusions of the analysis carried out on the method, we proceeded to solve the problem using successive iterations to approach the final solution. In each iteration the three zones, Zone 1, Zone 2 and Zone 3, were processed. (Figures 3, 4, 5 and 6).

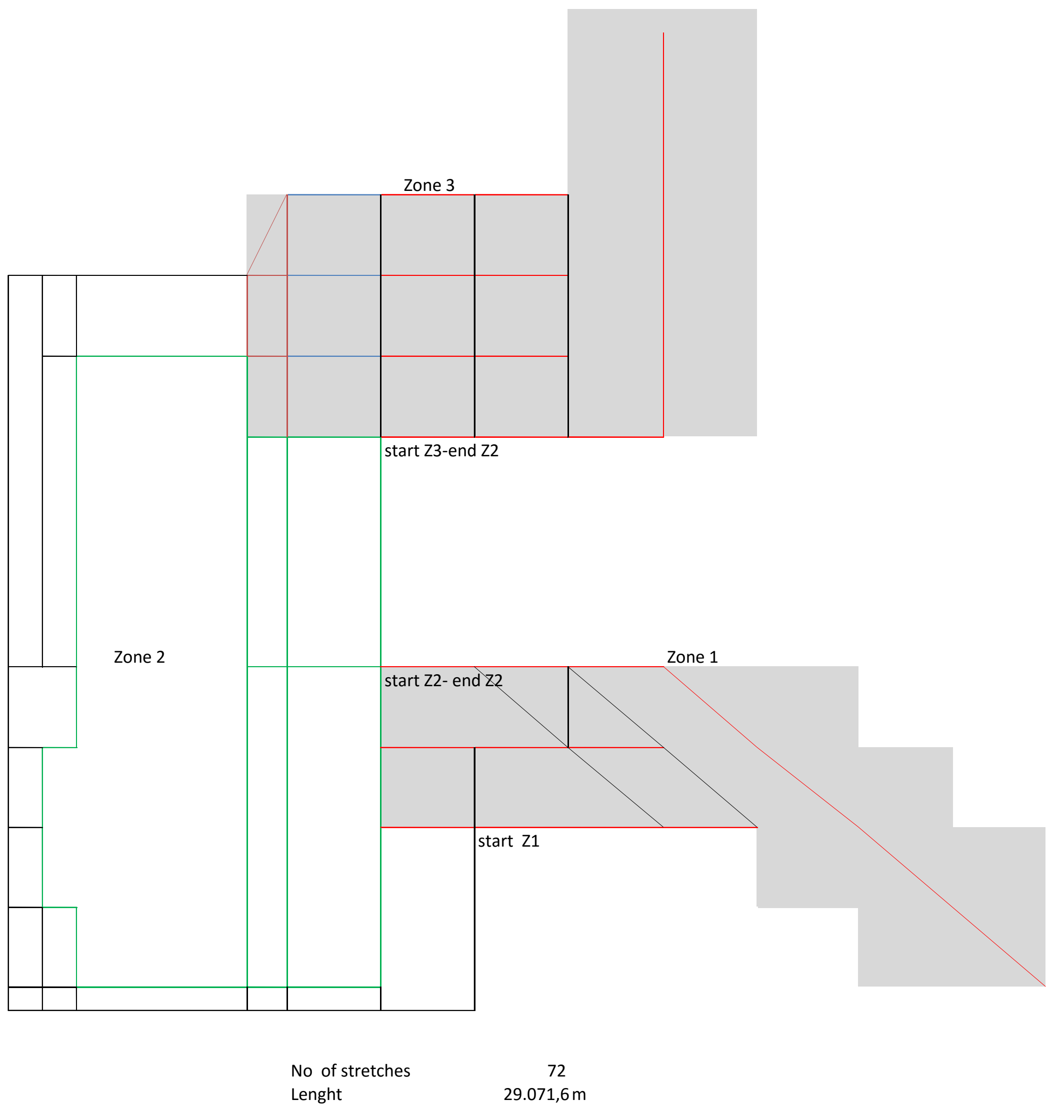

Figure3: Configuration of the manoeuvring area T4S used for the computational tests by zone

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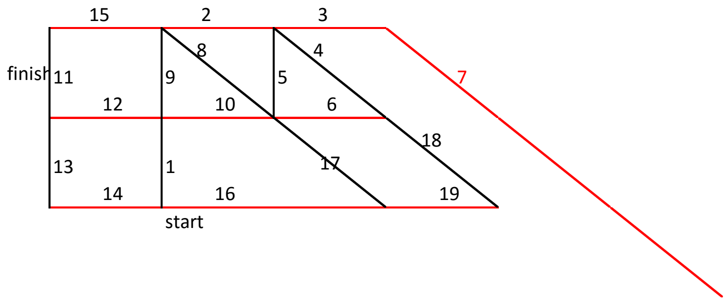

Figure4: Configuration of manoeuvring area T4S, Zone 1

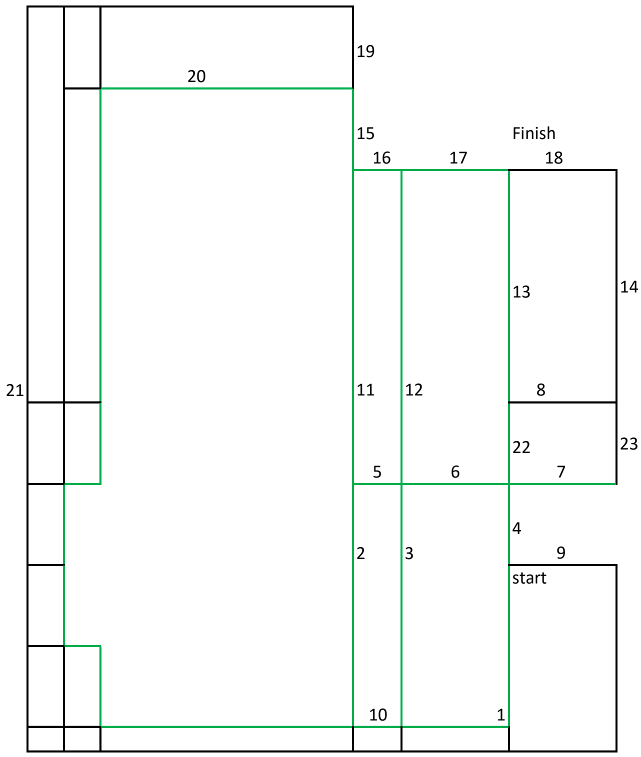

Figure5: Configuration of manoeuvring area T4S, Zone 2

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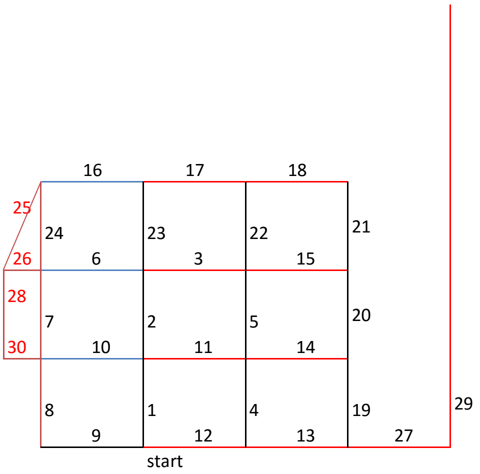

Figure6: Configuration of manoeuvring area T4S, Zone 3

Given the geometry of the manoeuvring area, H subsets of significant points were particularised into five subsets. We considered one landing runway, one take-off runway, one de-icing apron and, therefore, just one subset of stretches to access the de-icing area from the apron, and one apron.

$J_{RWY\text{-}Ai(fori=1)} = \quad J_{arr} = (2, 3, 6, 7, 10, 12, 14, 15, 16, 19)|_{Zn1} \subset Zn_1$

$J_{APR} = \quad J_{apron} = (1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 15, 16, 17, 20)|_{Zn2} \subset Zn_2$

$J_{APR\text{-}ZDe\text{-}icek\ (for\ k=1)} = \quad J_{accdice} = (7, 8, 24, 25, 26, 28, 30)|_{Zn3} \subset Zn_3$

$J_{ZDe\text{-}icek\ (for\ k=1)} = \quad J_{dice} = (6, 10, 16)|_{Zn3} \subset Zn_3$

$J_{RWY\text{-}Di\ (fori=1)} = \quad J_{dep} = (3, 11, 12, 13, 14, 15, 17, 18, 27, 29)|_{Zn3} \subset Zn_3$

The general problem-solving model is particularised for the manoeuvring area proposed (Fig. 7).

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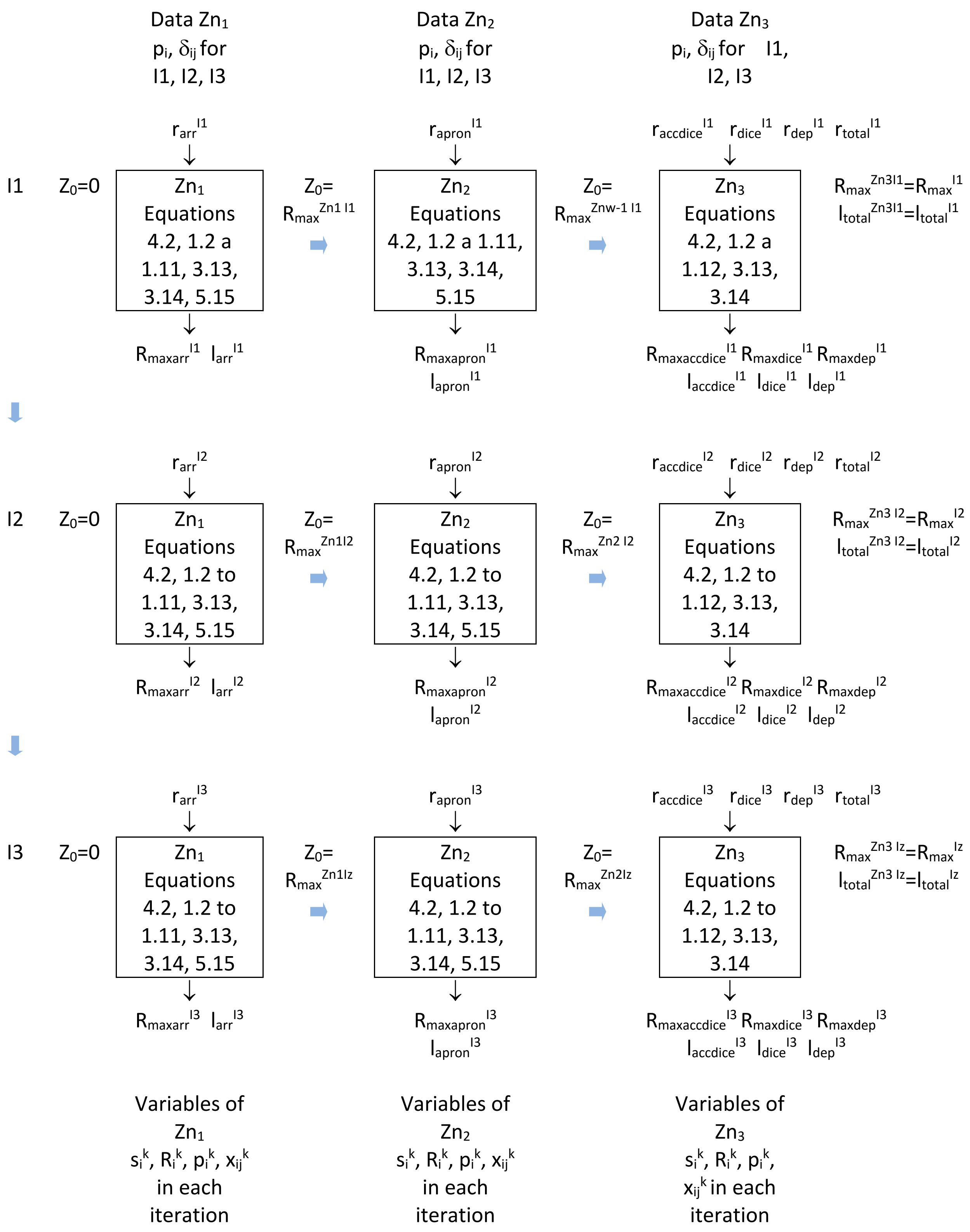

Figure7: Process to apply the particularised solution method to the manoeuvring area of T4S

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3.3. Computational Results

Figures 8, 9 and 10 demonstrates the results of the final iteration.

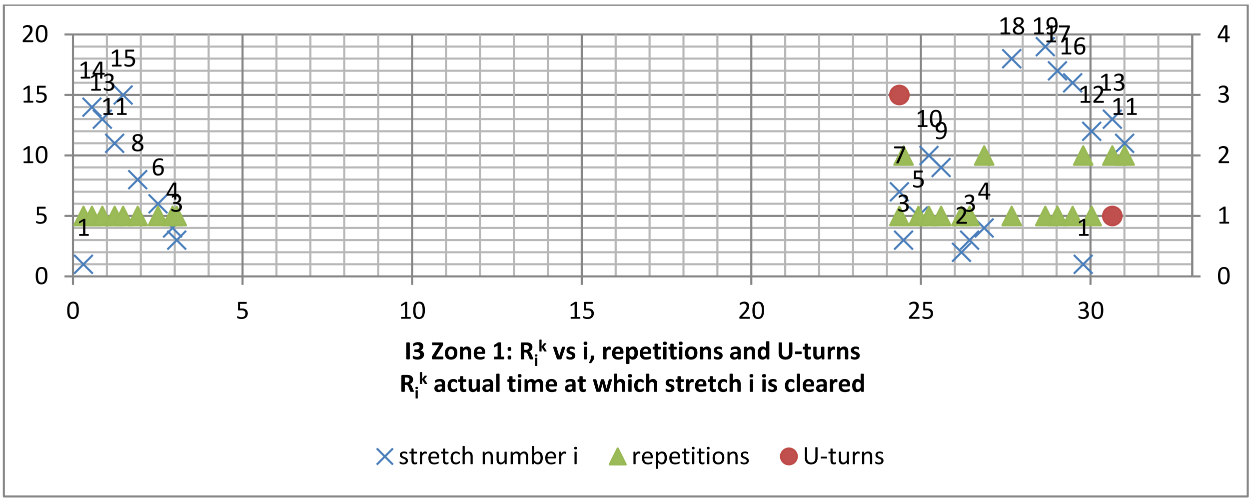

Figure8: Results Zone 1 Iteration 3

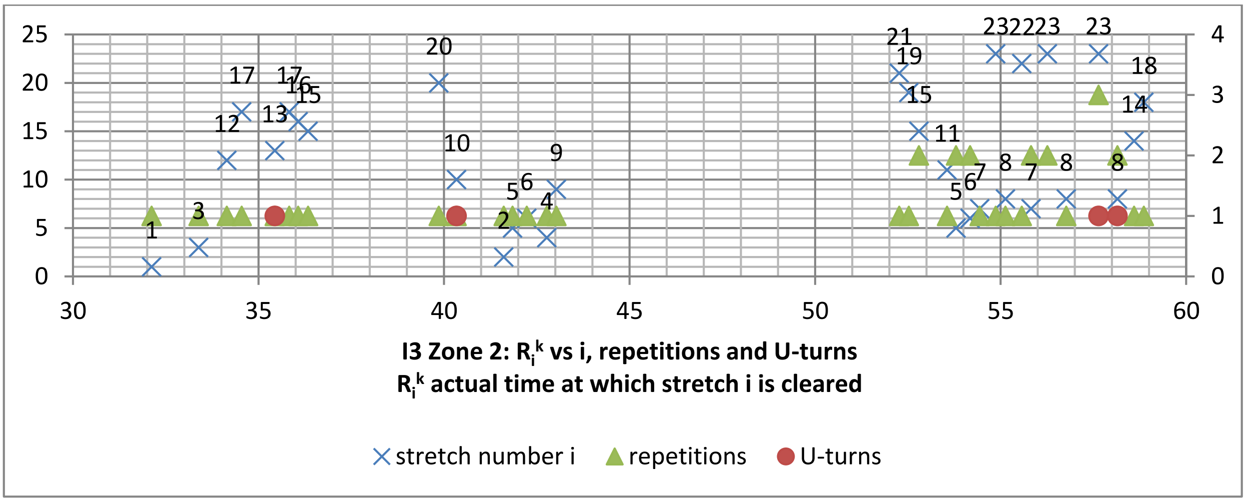

Figure9: Results Zone 2 Iteration 3

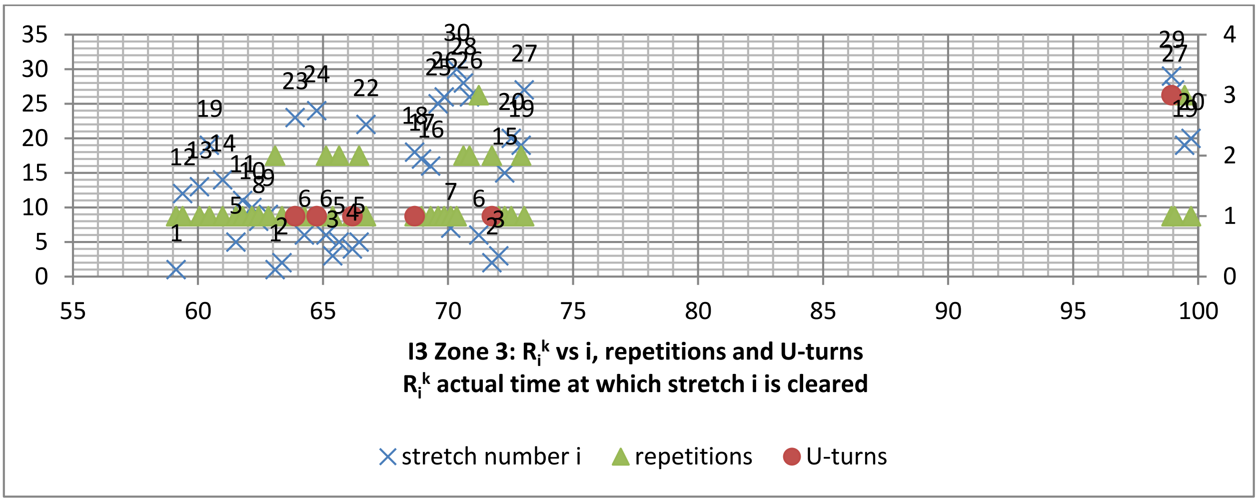

Figure10: Results Zone 3 Iteration 3

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4. Conclusions and Discussion

There is an optimal solution for removing snow from stretches of the manoeuvring area. In this article we have presented an algorithm for a single machine based on algorithms proposed by the authors Bianco et al. 1997 and Guinet 1993 for DMAN and AMAN problems, to resolve RM-MA problem, and a method of resolution based on an iterative process in which the manoeuvring area is divided into zones with a starting node and a final node.

Each zone must accommodate subsets of significant stretches from the point of view of Winter Operations. The plan covers runways, rapid exit taxiways and taxiways up to the apron. It also includes the stand apron, taxiways from the stand apron to the de-icing apron, take-off runways and taxiways providing access to the head-of-runway from the de-icing zone. The aim of the method proposed in this article is to optimise the time taken by a convoy of machines to remove snow. The algorithm takes account of the technology of the snow-clearing machines, and the width of the taxiways and runways. The results of the method, such as the estimated time taken to remove snow during the contingency plan, should be incorporated into the sequencing of arriving and departing flights.

5. References

References in indexed publications:

1. Bianco, L., Dell'Olmo, P. and Giordani, S., 1997. Scheduling Models and Algorithms for TMA Traffic Management. *Modelling and Simulation in Air Traffic Management eds*. 139-167.
2. Guinet A, 1993. Sequence-Dependent Jobs on Identical Parallel Machines to Minimize Completion Time Criteria. *International Journal Production Research*, 22(7), 1579-1594.

Other references:

1. AENA, S.A., 2013. 9th Winter Conference, Huesca, España. www.aena.es.
2. Eurocontrol, Airport CDM Coordination Group, 2009. Airport CDM steps to efficiency. http://www.euro-cdm.org/library/eurocontrol/airport_cdm_steps_to_efficiency.pdf.
3. European Aviation Safety Agency (EASA), 2010. Runway Friction and Aircraft Braking: The Way Forwardhttp://easa.europa.eu/system/files/dfu/events-docs-2010-11-03-EASA-Runway-Friction-Aircraft-Braking-Workshop-Summary-and-Conclusions.pdf.