MINIMIZING MOBILIZED SOIL VOLUMES DURING CONSTRUCTION OF LONGITUDINAL WORKS

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Gustavo Salerno, CPESC 2006, is a 1996 gold medallist in Engineering at the University of Buenos Aires, and obtained a Master of Business Administration degree from Austral University in 2001. Mr. Salerno has been very active in the field of erosion control in Argentina through his work as a constructor or advisor for many Argentine state agencies. He is now Vice President of INMAC S.A., where he has also acted as advisor for the application of erosion control products for many companies in Mexico, USA, China, Japan and Australia.

Eng. Gabriel Amores is an expert in the field of erosion control in Argentina through his work in national and international companies (he has been technical and economical manager of Maccaferri Gaviones Argentina, the subsidiary of the Italian firm). As President of his company, INMAC S.A., he has participated in the design and construction of erosion control works in many parts of the country and also in some Latinamerican countries. He has also offered a variety of courses on these themes and has been involved in many research projects.

Emilio Lecertúa and Pablo García, Engineers of the University of Buenos Aires, 2007, are young professionals that have already participated in many studies involving problems of erosion/sedimentation and pollutant transport involving numerical modeling. They are under contract at INA, and have contributed to some of INMAC research and development projects.

ABSTRACT

The algorithm implemented in software *DUCTO*, for the calculation of mobilized soil volumes during the construction of a pipeline route, already presented in Dallas 2010, is reformulated in order to obtain the longitudinal distributions of cut and fill volumes, with a 1 km resolution. The comparison of its results with those obtained manually based on the design, and/or those corresponding to the actually performed field works (difference between pre and post topographies), for two large pipeline projects in South America, indicates a reasonable accuracy. Some work is still necessary in order to improve the calculation of the fill volume distribution.

Key words: linear developments; Right-of-Way; pipeline route; mobilized soil volumes

1. INTRODUCTION

The construction of linear developments, such as oil and gas pipelines, requires the temporary uncover of a long strip of land (the pipeline route), and its grading before the pipeline digging operation. Both economical and environmental considerations lead to the requirement that the volume of mobilized soil be kept to a minimum. In Orlando 2011 (Salerno et al. 2011), the 'Green ROW Technology', a strategy developed to implement such a requirement, was described. On the other hand, in Dallas 2010 (Menendez et al. 2010), an automatic procedure to determine the total mobilized soil volume, implemented in software *DUCTO*, was presented. This procedure has been applied in practice, as a component of the Green ROW Technology, in order to select, among various pipeline route alternatives, the one implying the minimum total mobilized soil volume.

After successful applications of *DUCTO*, an additional challenge was undertaken, namely, not only providing the total cut and fill-soil volumes, but also their longitudinal distributions with a 1 km resolution. This has required the reformulation of the algorithm, and the introduction of a new set of criteria.

In the present paper, the new algorithm is described, and validated through its application to two pipeline projects, for which INMAC participated by applying the Green ROW Tehcnology: Pagoreni project (80 km, Perú), and Cashiriari project (46 km, Perú). The results provided by *DUCTO* are compared with those obtained manually based on the design, and/or those corresponding to the actually performed field works (difference between pre and post topographies). Sensitivity of results to model parameters is also analyzed.

2. ALGORITHM

The original algorithm proceeded through the following steps: (a) segmentation of the pipeline route; (b) longitudinal grading; (c) transversal grading (Menendez et al. 2010). The new algorithm introduces changes in the segmentation step, and combines the two grading steps into a new procedure with several steps.

The segmentation step to move from the 'original set of nodes' to the 'extended set of nodes' is performed as explained in the previous paper (Menendez et al. 2010), but, instead of getting intersection nodes, a new series of evenly spaced nodes is built (Figure 1). The distance between nodes is chosen of the order of 10 m. The elevations corresponding to these nodes are calculated through bilinear interpolation (Figure 2). In this way, the terrain profile along the pipeline route is obtained.

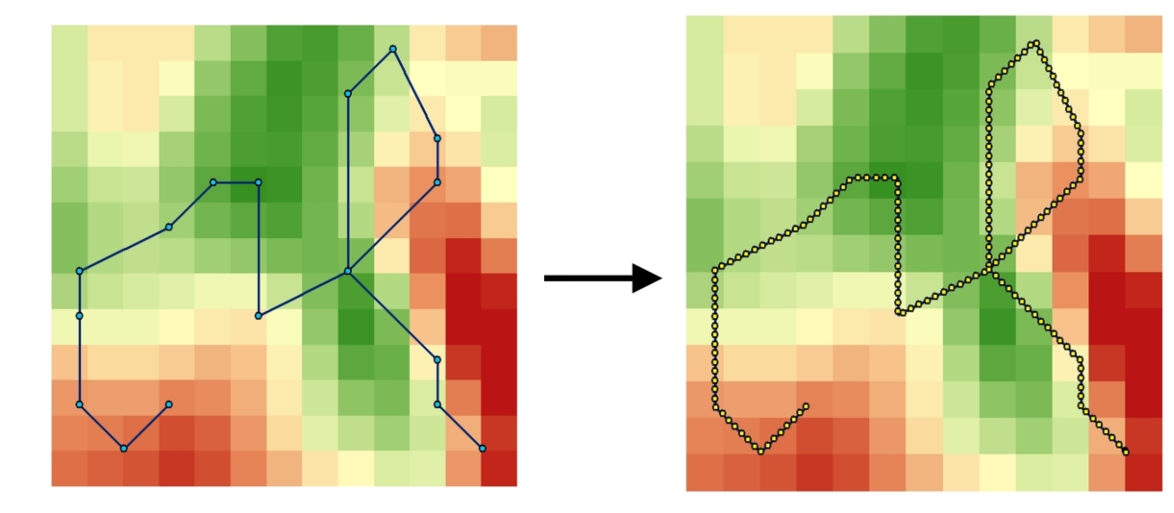


Figure 1. Segmentation of the pipeline route. The quadrangles indicate the elevations of the cells corresponding to the DEM.

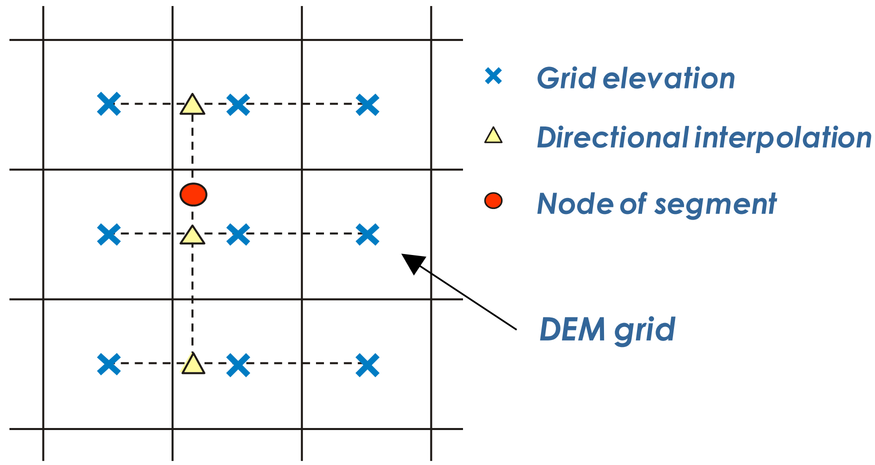


Figure 2. Bilinear interpolation.

The next step is to calculate the design pipeline route profile. This includes the following operations:

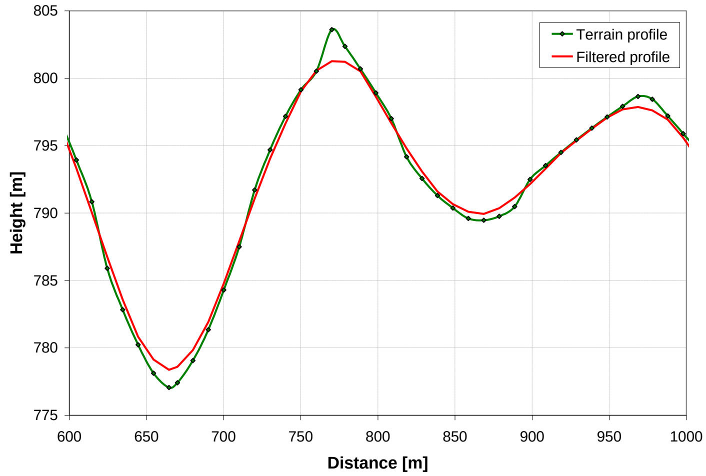
i. filtering the terrain profile through a moving average, with a 100 m long window (Figure 3a);

ii. checking (Figure 3b) and eventual correction (as explained in Menendez et al. 2010) of the angle in the vertical plane, in order to avoid strong pipe bending;

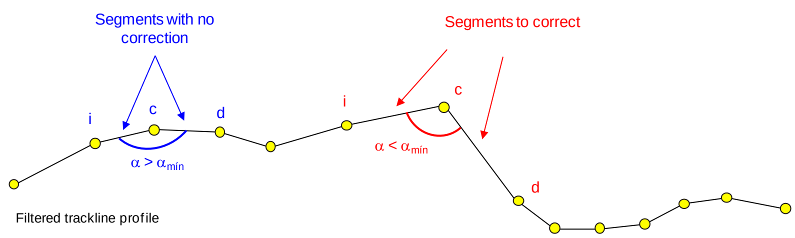
iii. shifting downward the profile (Figure 3c), so as cutting dominates over filling, where the scale of the downward shift is the mean value of the positive differences between the terrain profile and the filtered/corrected terrain profile.

A criterion is introduced in order to distinguish between mild and strong steepness. A mean slope distribution of the pipeline route profile is obtained by taking the spatial series of local slopes between successive nodes, and filtering it out with a 250 m long window. Based on it, stretches are determined where the mean slope is lower than 20% – which is considered as a mild steepness – and higher than 20% – considered as a strong steepness –. For the mild steepness case, the downward shift is directly taken equal to the scale; but for the strong steepness case, the downward shift is fixed as the scale plus the standard deviation of the series of positive differences between the terrain profile and the filtered/corrected terrain profile. In this way, the stronger irregularities, associated to larger steepness, are taken into account. In any case, the route level is not allowed to be higher than the terrain level.

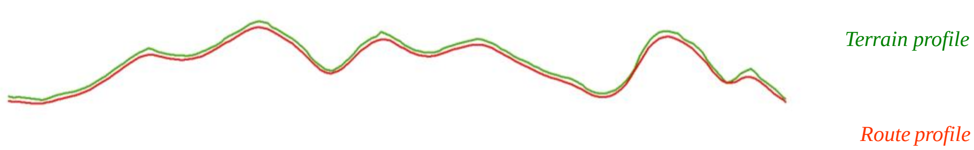
The final step is to perform the grading of the route, where different cut and fill operations are performed, depending on the cross section type: box, peak or slope (Figure 4). Note that for the peak and slope cases, fences might be necessary in order to contain the infill. The fences height is not allowed to be higher than 1.5 m. The route width and ROW are reduced along the stretch with peak section type.



a) Filtering

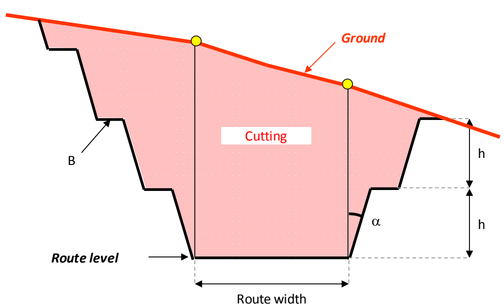


b) Angle checking

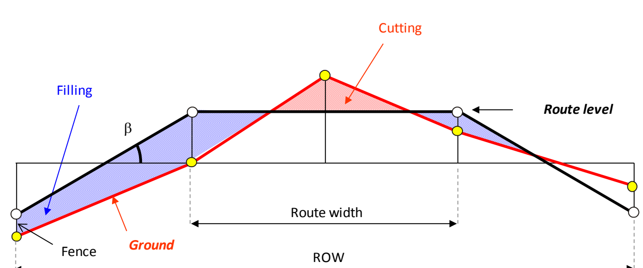


c) Final profile

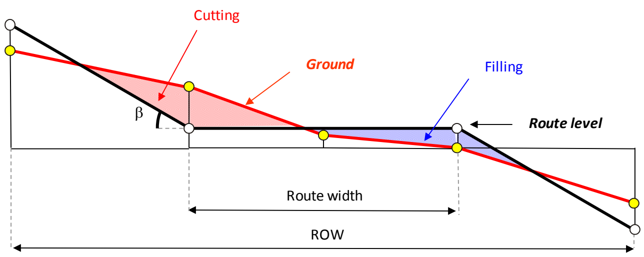
Figure 3. Pipeline route profile calculation.



a) Box



b) Peak



c) Slope

Figure 4. Grading for different cross section types

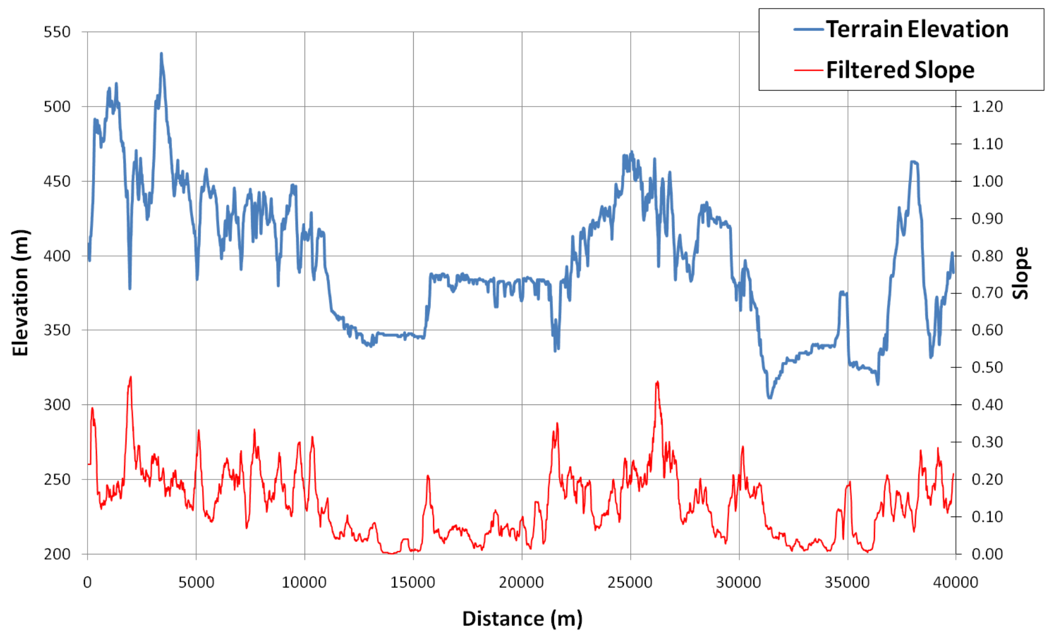
3. VALIDATION

Figure 5 indicates the locations of the duct projects in South America where *DUCTO* was applied. For Pagoreni and Cashiriari, both located in Perú, data on the longitudinal distribution of mobilized soil was available, so they were used in order to validate the described methodology.

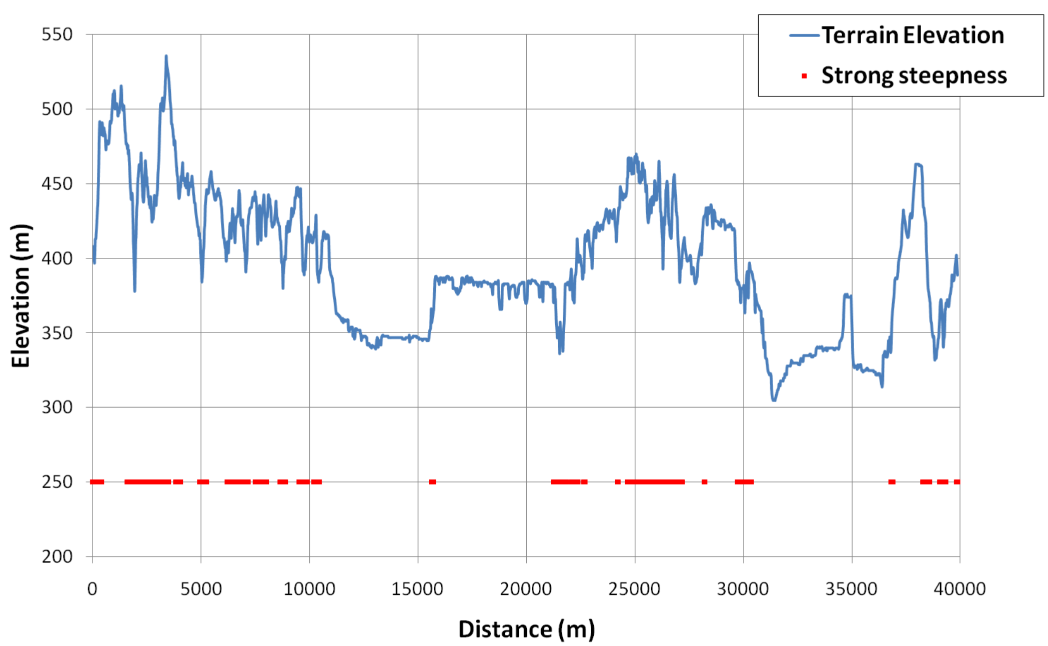
Figure 5. Location of duct projects

Pagoreni project is a 80 km long route, divided into four sectors: (i) 'Pagoreni B – Mipaya', 40 km; (ii) 'Empalme – Pagoreni West', 3 km; (iii) 'Malvinas – Pagoreni A', 22 km; (iv) 'Nuevo Mundo – Kinteroni', 15 km. As an illustration, Figure 6a shows the longitudinal distribution of filtered slope for the first sector, from which the strong steepness stretches are determined (Figure 6b).

The longitudinal distribution of cut volumes calculated with *DUCTO* for the first sector of Pagoreni project is presented in Figure 7a, for the following parameter values: route width = 12 m; ROW = 25 m; minimum pipe bending angle = 168°; lateral slope = 27°, berm height = 3.5 m; berm width = 1.0 m. It is compared with the values obtained manually based on the route design. The general agreement is considered as very satisfactory. In Figure 7b the relative difference between them is plotted. It is observed that locally the automatic calculation may provide values about double or half the manually calculated ones. The total cut volume for this sector, according to *DUCTO*, is 762,500 m^3, 11% lower than calculated manually, a difference considered quite satisfactory.

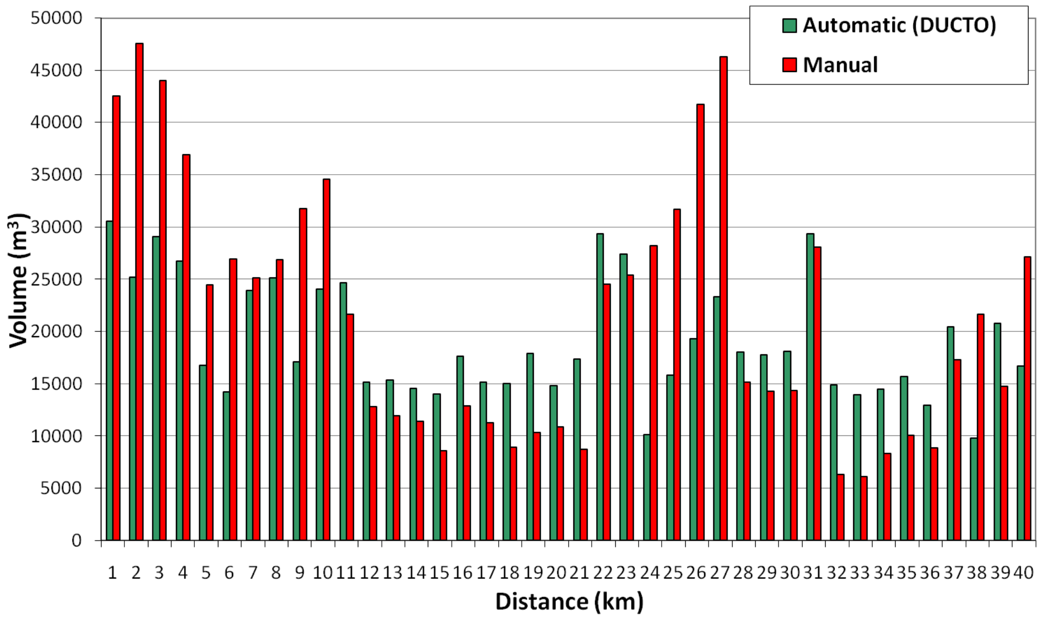


a) Filtered slope

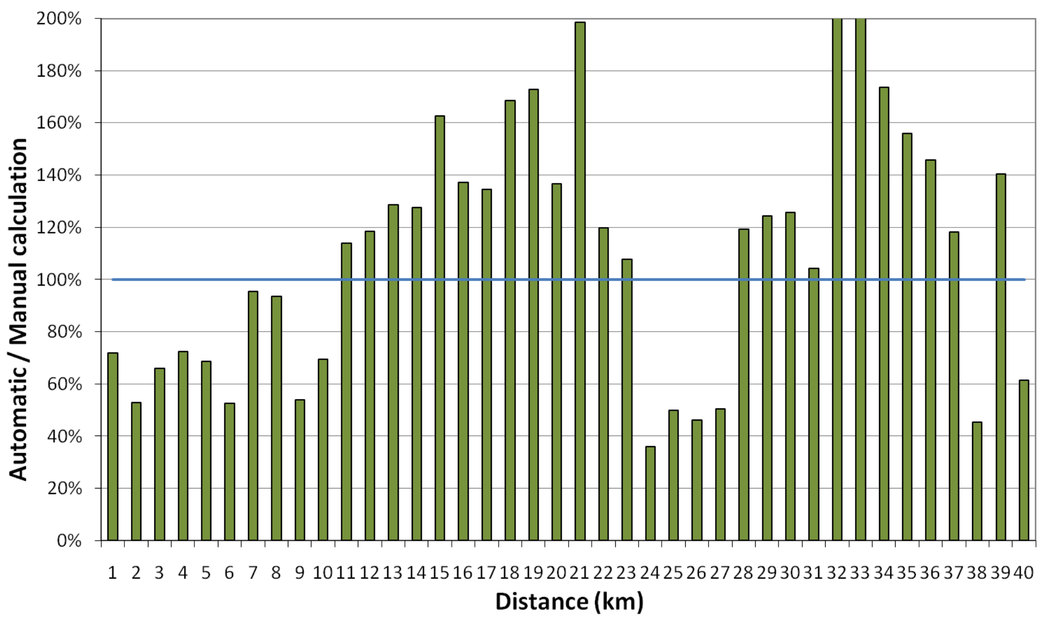


b) Strong steepness stretches

Figure 6. Characterization of ‘Pagoreni B – Mipaya’ sector.



a) Comparison between automatic and manual calculation



b) Relation between automatic and manual calculation

Figure 7. Cut volume distribution for 'Pagoreni B – Mipaya' sector.

Figure 8 shows the comparison of longitudinal distributions of fill volumes for the same sector. It is observed that calculations with *DUCTO* are consistently higher than the manual ones, indicating that some extra criteria should still be introduced in the automatic calculation in order to capture the practical strategy implemented manually. However, being conservative, the prediction with *DUCTO* is still useful for planning purposes.

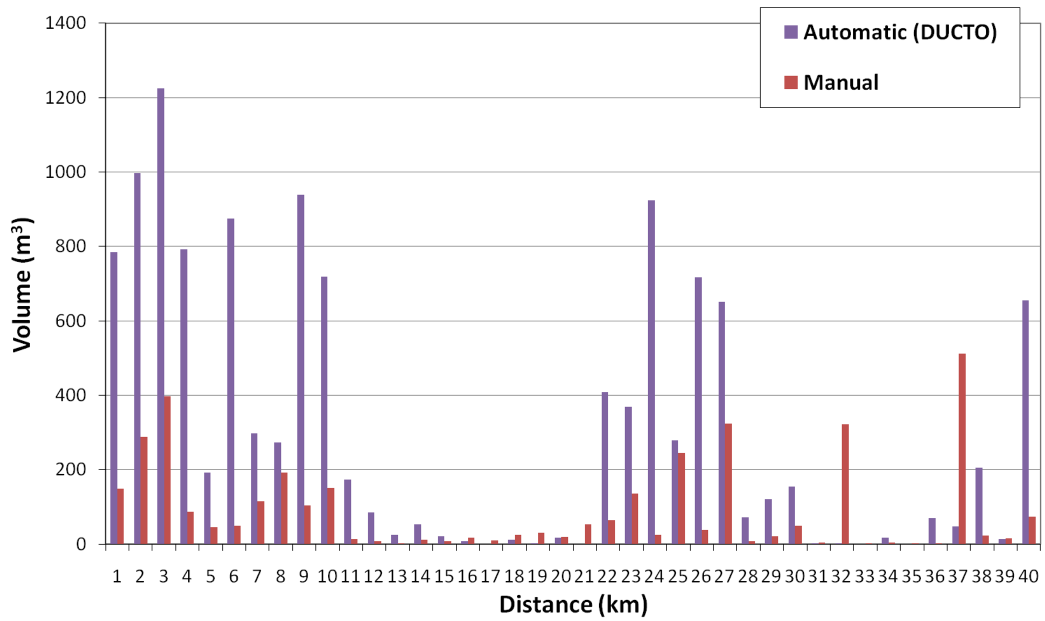
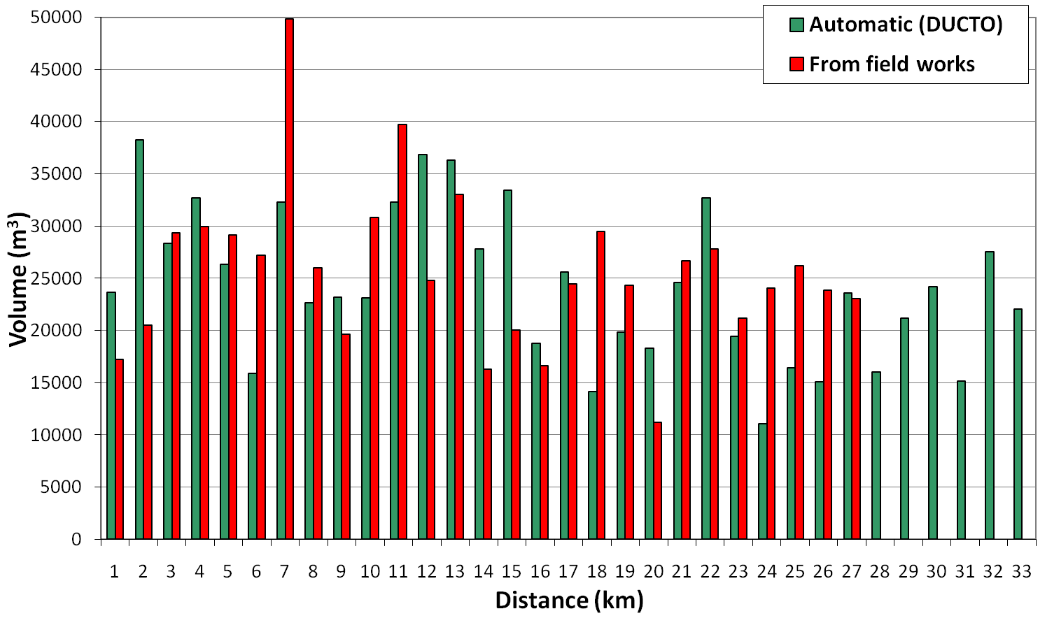


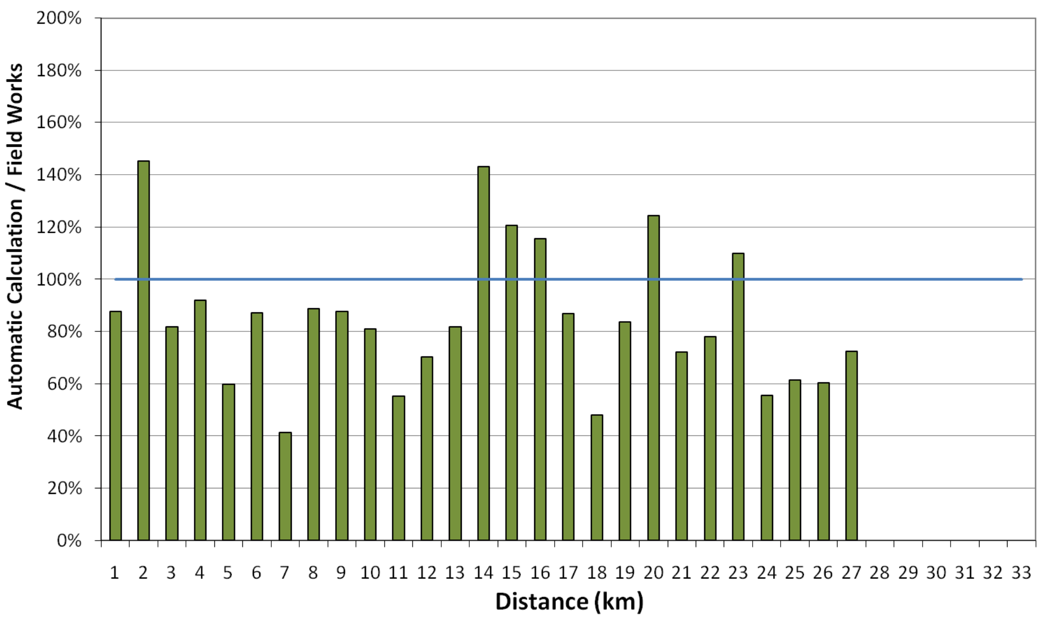
Figure 8. Fill volume distribution for 'Pagoreni B – Mipaya' sector.

Chashiriari project is 46 km long, and it is divided into two sectors: (i) 'Malvinas – Cashiriari', 33 km; (ii) 'Cashiriari I – Cashiriari III', 13 km.

Figure 9a presents the longitudinal distribution of cut volumes calculated with *DUCTO* for the first sector of Cashiriari, where it is compared with the values corresponding to the actually performed field works (difference between pre and post topographies), for the following parameter values: route width = 12 m; ROW = 25 m; minimum pipe bending angle = 168°; lateral slope = 27°, berm height = 2.0 m; berm width = 1.2 m. Once again, the general agreement is considered as very satisfactory. The relative difference (Figure 9b) is now lower, with maximum values in the approximate range ±40%. The total cut volume for this sector , calculated with *DUCTO*, is 672,700 m^3, only 3% lower than the value obtained by topography difference.



a) Absolute values



b) Relative difference

Figure 9. Cut volume distribution for 'Malvinas – Cashiriari' sector.

4. SENSITIVITY

Numerical experiments were performed in order to establish the sensitivity of the results provided by *DUCTO* to variations in the model parameters. The following parameters were varied, within practical limits: route width (from 12 to 11 m), ROW (from 25 to 17 m), lateral slope (from 27 to 6°), berm height (from 3.5 to 2.0 m), and berm width (from 1.0 to 1.2 m); variations lower than 10% were obtained for the total cut volume, i.e., a relatively low sensitivity.

The sensitivity to the DEM is significant, as expected. When SRTM data are used, instead of a detailed topographic survey, variations of the order of $\pm$50% are obtained for the total cut volume.

5. CONCLUSIONS

The reformulation of the algorithm and criteria introduced in software *DUCTO*, have allowed the calculation of the longitudinal distribution (with a 1 km resolution) of cut and fill-soil volumes associated to the construction of a pipeline route, with a reasonable accuracy.

Some work is still necessary in order to improve the calculation of the fill volume distribution.

5. REFERENCES

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