# METODOLOGY OF USING TERRAIN PASSABILITY MAPS FOR PLANNING THE MOVEMENT OF TROOPS AND NAVIGATION OF UNMANNED GROUND VEHICLES

Krzysztof Pokonieczny[1], Wojciech Dawid[1],

[1]Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, 00-908, Poland

*Correspondence to*: Krzysztof Pokonieczny[1] (krzysztof.pokonieczny@wat.edu.pl)

https://doi.org/10.31490/9788024845050-12

## Abstract

The determination of the route of movement is a key factor which allows the navigation. In this abstract the authors present the methodology of using different resolution terrain passability maps for graph generation, which allow of determination of the optimal route between two points. The proposed methodology allows of determination of routes in various variants – longer route, but avoiding all terrain obstacles with a wide curve, or shorter route, but more difficult to overcome. The paper shows also possibilities of implementation of the methodology for the movement of large military operational units moving in a 1-kilometer width corridor as well as for determining routes for single vehicles or Unmanned Ground Vehicles (UGVs) by using detailed maps of passability.

**Keywords:** maps of passability, pathfinding, UGV navigation, Cross Country Movement

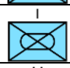
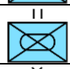
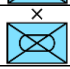
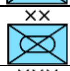
## INTRODUCTION

Planning avenues of approach is crucial for the success of conducted military operation. Corridor that is to be used for the troops movement must be optimal, what means that it should both avoid all terrain obstacles and be as short as possible. To meet both aforementioned conditions, it is necessary to have actual and appropriately detailed passability maps. These maps allow us to determine the possibility of overcoming the terrain off-road in all weather conditions. In its basic version (provided in NATO standards) the terrain is divided into three classes: passable terrain (GO), hardly passable terrain (SLOW GO) and impassable terrain (NO GO). Until now the authors have conducted researches that significantly extended the definition of three-classes passability maps. They published (Dawid & Pokonieczny, 2020; K. Pokonieczny, 2018) methodologies of different detailed maps development on the basis of various repositories of spatial data. This article presents the methodology of using aforementioned maps for determining the optimal route, which takes conditions of the terrain passability into account. There will be presented results concerning route determination in various configurations for military operational units as well as for determining routes for single vehicles or even UGVs by using detailed passability maps. Besides, the aim of the research was to find a method of route generation in two basic configurations: longer, avoiding all terrain obstacles, and shorter, but harder to overcome. It allows of a variant approach to the planning process and selecting a route that can be fully defined as “optimal”.

## METHOD

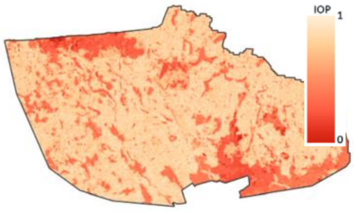
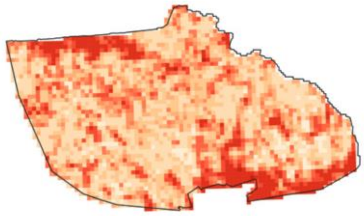
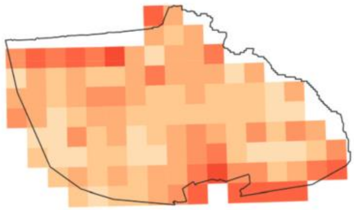
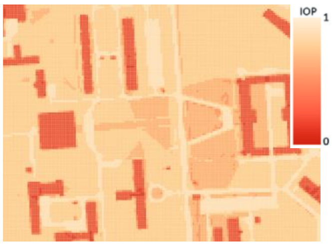
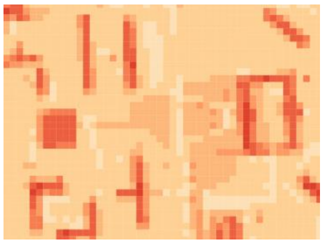
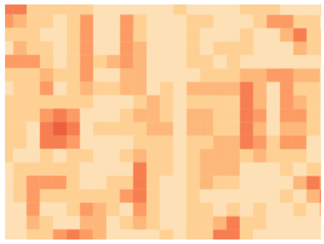
The passability maps, which development methodology has been presented in the publication (Krzysztof Pokonieczny, 2017), were used to determine the route. They are based on the terrain division into fields of the same area (in presented research they were squares). The various size of these fields allowed of obtaining different detailed maps. It is very significant for the possibility of using these maps for planning operations and determining routes for military units of various level of command because, taking into account width of the movement corridor defined in the instruction (*Field Manual 34-130 Intelligence Preparation of the Battlefield*, 1994) it is easy to set a size of a primary field the passability map should be built of (Table 1).

**Table 1.** Relation between troop size and size of a primary field (Krzysztof Pokonieczny & Mościcka, 2018)

| Troop size | Troop symbol | Size of primary field | Width of avenue of approach |
|---|---|---|---|
| Platoon |  | 100 m | 200 m |
| Company |  | 200 m | 500 m |
| Battalion |  | 500 m | 1 500 m |
| Brigade |  | 1 000 m | 3 000 m |
| Division |  | 2 000 m | 6 000 m |
| Corps |  | 5 000 m | 15 000 m |

The index of passability (IOP) is determined for each primary field. It is computed on the basis of elements of land cover and landform which are located within this field. For the calculation of IOP the military vector database was used – Vector Map Level 2 (VML2) (*Military specification MIL-V-89032 Vector Smart Map (VMAP) Level 2*, 1993, p. 2). The index was determined to be a continuous value from 0 (impassable terrain) to 1 (wholly passable terrain with awesome tactive properties) (Table 2).

**Table 2.** Examples of passability maps

| 200 x 200 m | 1 000 x 1 000 m | 2 000 x 2000 m |
|---|---|---|
|  |  |  |
| **3 x 3 m** | **10 x 10 m** | **20 x 20 m** |
|  |  |  |

To determine the optimal route with use of passability maps, they must be converted into a graph which consists of nodes and edges. The developed methodology assumes that nodes are the centroids of primary fields. Nodes were connected with edges which were assigned a cost of overcoming them. The cost is an average passability value of two neighboring primary fields minus 1 (see Figure 1).

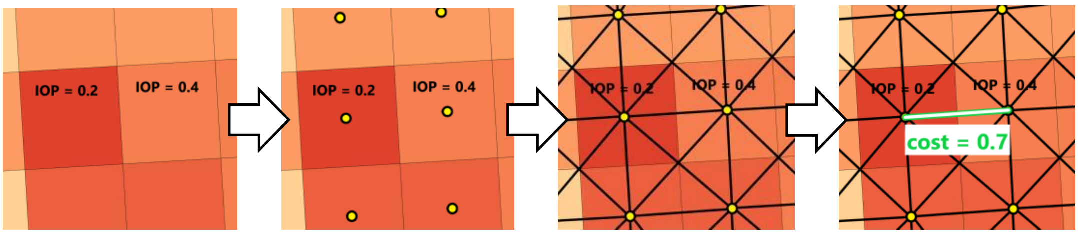



**Fig. 1.** A way the developed system generates a graph.

On the basis of generated graph, the optimal route between two points has been determined (Figure 2). In this research the route was generated on the basis of primary fields of 1000 by 1000 m size (for planning the movement of troops) and for inconsiderable primary fields of 3 by 3 m size. The IOP of the latter was determined on the basis of the most detailed cartographic material which is available in Poland – the base map in scale of 1:500. This detailed passability map can be used for determination of the optimal route e.g. for UGV or a single vehicle.

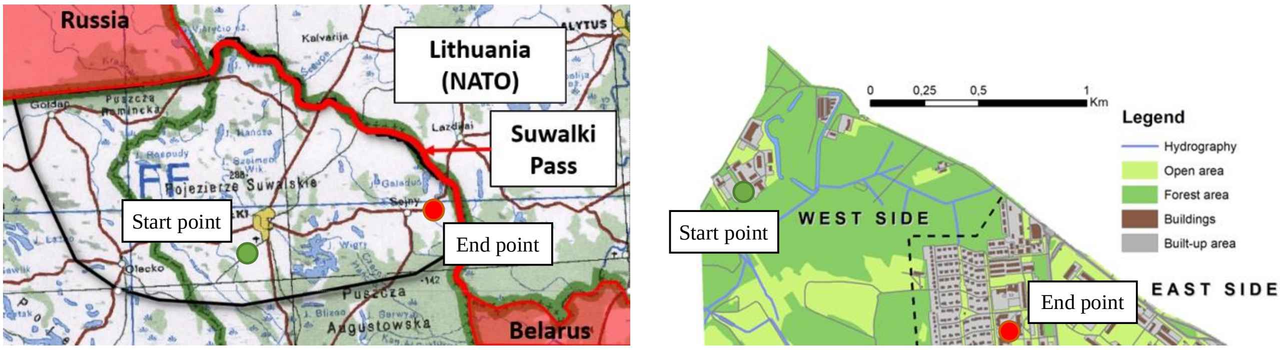



**Fig. 2.** The area of research and start and end points of generated route. On the left – area for a field of 1000 by 1000 m size, on the right – 3 by 3 m size.

On the basis of generated graph the optimal route between two points has been determined with use of Dijkstra's algorithm. It allows of finding the shortest path in a graph with nonnegative weights (Schulz et al., 1999). The algorithm realizes so-called greedy approach. In each iteration one of the unvisited nodes, which can be reached with the lowest cost, is chosen. After the determination of a path to a specific node it will not be modified during the execution of the rest of the algorithm.

Routes were generated for different IOP values. There were used 3 methods that compute them:

- Finding the route directly for the computed IOP values (based variant, denoted "variant no. 1")
- Finding the route for modified IOPs by determination of their new values with use of a function:

$$IOP_{new} = \frac{1}{1+e^{-\beta \cdot IOP}} \quad (1)$$

  Tests were conducted for a β parameter totaling from 2 to 18. The using of the function (1) allowed of augmentation of differences between impassable and passable areas (Figure 3).

- Finding the route for modified IOPs by determination of their new values with use of a function:

$$IOP_{new} = \frac{-e^{\frac{1}{IOP-1}}}{\beta+0.5} \quad (2)$$

  Thanks to it, the IOPs distribution has been flattened with simultaneous decrease of the differences between passability indexes (Figure 3).

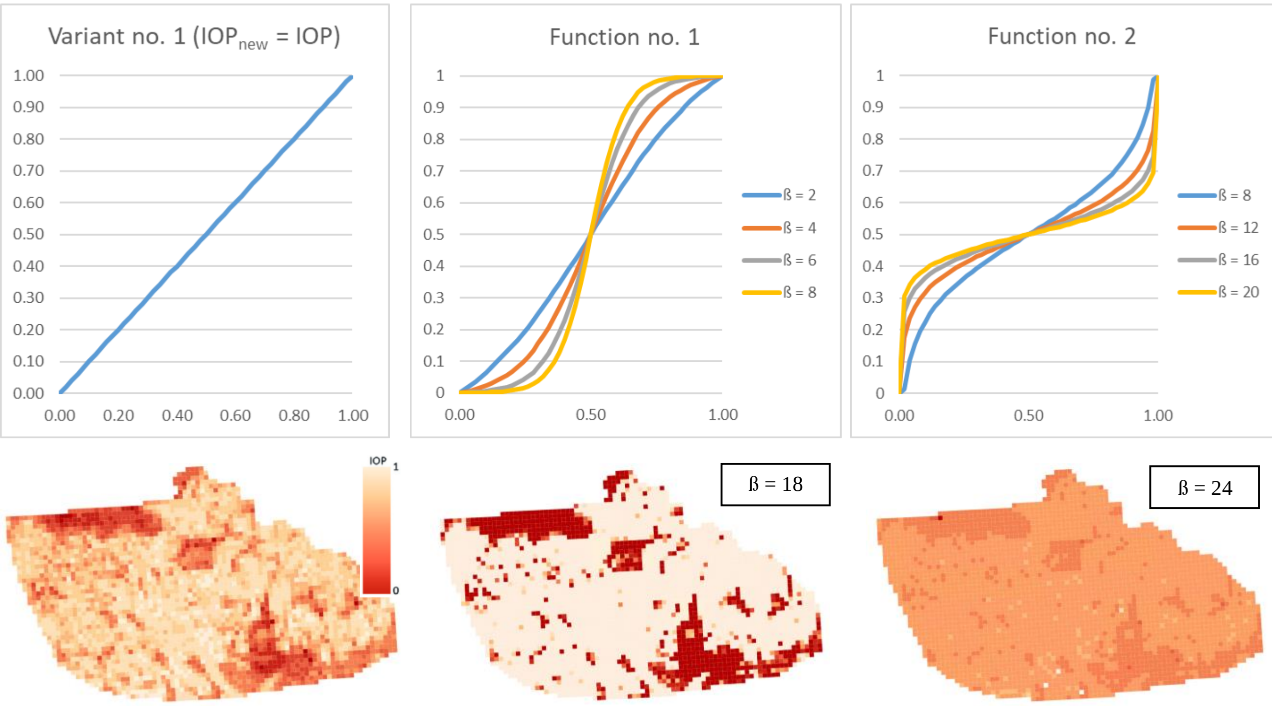



**Fig. 3.** Charts of used functions with different values of β parameter. Belowe there are visualizations of passability maps created on the basis of the above functions.

In the article, which will be an extension of this abstract, there will be presented results for different sizes of primary fields as well as for different algorithms of determination of the optimal route (e.g. A* search algorithm).

## RESULTS AND DISCUSSION

Figure 4 presents a visualisation of routes for both configurations of the size of primary fields. There is also shown an outcome, as a resulting route, of a function (1) and (2) in dependence of various β coefficient value.

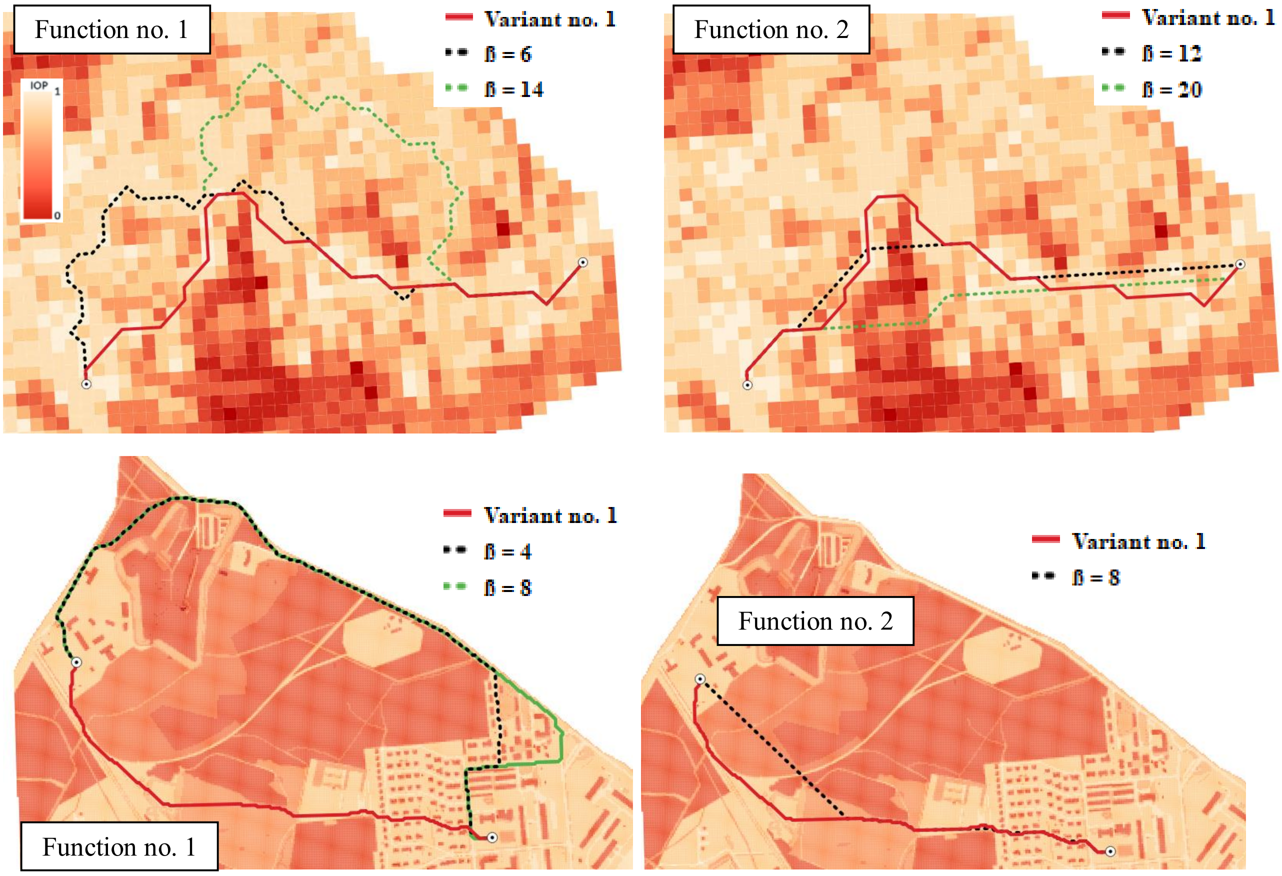



**Fig. 4.** Visualization of generated routes obtained for various values of β parameter. Above – for primary field 1000 by 1000 m, below – 3 by 3 m.

Resulting routes clearly prove that with the increase of a β coefficient with use of function (1) the obtained route gets longer. It is noticeable that its course avoids areas of a worse passability. Along with the rise of a β coefficient the route goes on an easier to overcome terrain, somehow avoiding impassable areas with a wider and wider curve. The reason of that is the "stretch" of IOPs distribution resulting in augmentation of differences between them. It practically means that lower indexes of passability (from 0 to 0.5) get progressively lower, however, indexes greater than 0.5 increase and become close to 1. The use of function (2) has an opposite effect – the determined route is shorter along with the increase of β coefficient. Its shape is more and more close to the straight line between two points, which connects start and end point in the shortest way. Its direct reason is a flattening of IOPs distribution which practically makes the differences between obtained indexes of passability smaller.

These dependences are visualized in charts (Figure 5) presenting how the length of route and an estimator, which measures the “difficulty” of overcoming the route (average cost of overcoming 1 kilometer of designated route), influences the change of β coefficient. The aim of a determination how the average cost of overcoming each primary field changes, the standard deviation of costs of overcoming subsequent primary fields, followed by the route, has been calculated.

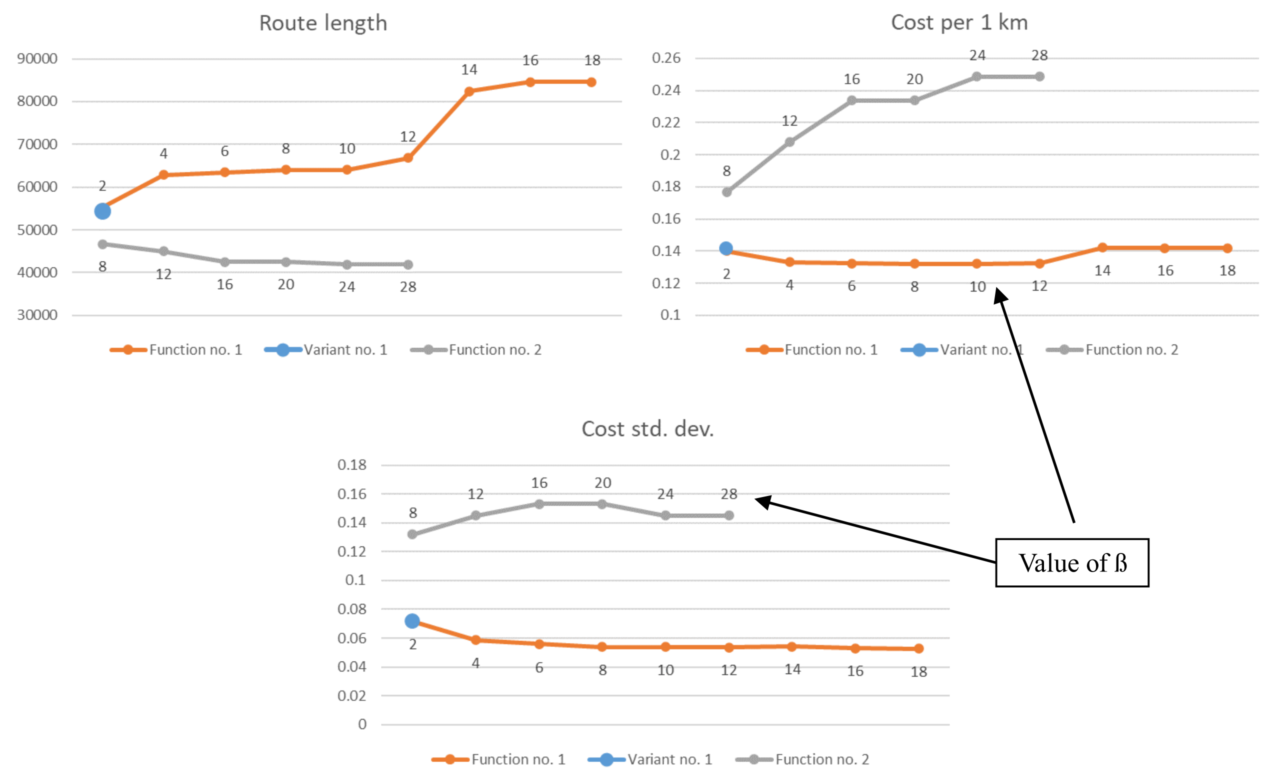



**Fig. 5.** Charts presenting changes of: route length, cost per 1 km and its standard deviation in dependence of used function and β coefficient value.

High standard deviation demonstrates that the variability of passability conditions is great and occurs when function (2) is used. The use of function (1) causes that the route, despite being longer, passes through the primary fields which indexes of passability change slightly and which passability is good or very good.

## CONCLUSIONS

Methodology proposed in this abstract shows, on the basis of developed passability map built of square primary fields, the way of obtaining a graph allowing of finding the optimal route. As a matter of fact that developed passability maps take most land cover elements into account, the generated route is credible and the use of Dijkstra’s algorithm makes that it can be treated as optimal. It emerged that conducting the modification of indexes of passability, on the basis of which graphs, and consequently routes are generated, was an interesting experiment. The use of function (1) allowed of obtaining a longer, but crossing well passable terrain, route (this route can be called “convenient”). Function (2) made that the route is significantly shorter but is leading through the areas of a worse passability (this route can be called “shorter but harder”). Such variant approach increases the possibility of planning the movement of troops or the determination of e.g. UGV movement. Presented methodology is universal because it can be used for planning the movement in a wide maneuver corridor (1 kilometer) as well as for the some-meter corridor on the basis of detailed maps of passability. It is worth mentioning that the module of route generation is an integral part of an informatic system, which provides fully automatic development of passability maps, their conversion into graphs and also an automatic route generation. The area of application of constructed system is very wide because, except for planning the movement of large military units or UGVs, the use of detailed passability maps is of key importance for the crisis management, where the possibility of reaching the area outside the road network can be crucial for a success of the salvage operation.

## REFERENCES

Dawid, W., & Pokonieczny, K. (2020). Analysis of the Possibilities of Using Different Resolution Digital Elevation Models in the Study of Microrelief on the Example of Terrain Passability. *Remote Sensing*, *12*(24), 4146. https://doi.org/10.3390/rs12244146

*Field manual 34-130 Intelligence Preparation of the Battlefield*. (1994). Headquarters, Department of US Army, Washington.

*Military specification MIL-V-89032 Vector Smart Map (VMAP) Level 2*. (1993). National Imagery and Spatial Agency.

Pokonieczny, K. (2018). Comparison of land passability maps created with use of different spatial data bases. *Geografie-Sbornik CGS*, *123*(3), 317–352. Scopus. https://doi.org/10.37040/geografie2018123030317

Pokonieczny, K., & Rybansky, M. (2018). Method of developing the maps of passability for unmanned ground vehicles. *IOP Conference Series: Earth and Environmental Science*, *169*(1), 012027. https://doi.org/10.1088/1755-1315/169/1/012027

Pokonieczny, Krzysztof. (2017). Automatic military passability map generation system. *2017 International Conference on Military Technologies (ICMT)*, 285–292. https://doi.org/10.1109/MILTECHS.2017.7988771

Pokonieczny, Krzysztof, & Mościcka, A. (2018). The Influence of the Shape and Size of the Cell on Developing Military Passability Maps. *ISPRS International Journal of Geo-Information*, *7*(7). https://doi.org/10.3390/ijgi7070261

Schulz, F., Wagner, D., & Weihe, K. (1999). Dijkstra's Algorithm On-Line: An Empirical Case Study from Public Railroad Transport. In J. S. Vitter & C. D. Zaroliagis (Eds.), *Algorithm Engineering* (pp. 110–123). Springer. https://doi.org/10.1007/3-540-48318-7_11