Relative Information Modelling based Optimization for Asphalt Pavement Renovation

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ABSTRACT

Different possibilities to utilize information modelling and automation in roadway maintenance and renovation, have been studied in Finland during 2010 – 2014. Mobile laser scanning was used for the initial data surveys. For the surveys and later design and construction phases, there are generally two alternative methods available for the executions: absolute or relative optimization.

In the absolute method, coordinates xyz are accurately measured in relation to the used global coordinate system using reference signal points with appropriate intervals. In the design phase, the absolute point cloud enables the geometric optimization of the whole length of the road. In the construction phase, machine control can be done using automated 3-D machine control system in the global coordinate system.

In the relative method, coordinates xyz are measured in relation to the existing road surface without using any reference signal points. In the design phase this relative point cloud enables the specific optimization for each of the selected road parts having some unevenness to be fixed. In the construction phase, machine control can be done using a guidance principle, where a human operates the machine and the blade using a tablet user-interface with RTK-GNSS positioning showing the XY positioning of the blade and the needed asphalt fill or milling cut in z direction.

The experiments of the relative method were made in real construction projects of Vt6 (Koskenkylä – Kouvola) and Kt55 (Porvoo) in Finland during 2013 – 2014. According to the achieved results, the relative optimization method is accurate enough for the renovation needs of local unevenness of roads. It is much cheaper than the absolute method and the material savings are remarkable compared to the traditional method, where no surveyed information is used. The relative method does not apply to the road parts, where absolute geometry dependences are critical.

Keywords – Asphalt Pavement; Information modelling; Maintenance; Mobile laser scanning; Renovation

1 Introduction

1.1 Background

In traditional renovation process design is usually made only by using road register data and possible site visits and visual observations. That leads to the situation were the asphalt material used to fixed unevenness spots is more or less indefinite. In traditional renovation process, the milling and the paving are made in fully 2-D on sites.

The utilization of Building Information Modeling (BIM) and model based 3-D control of work machines have increased a lot in new road construction in Finland as well as in other Nordic Countries. This development has been much slower in the field of road maintenance and rehabilitation. In Finland, as a part of the Infra FINBIM research work packet a special effort to study and develop the process of road maintenance has been active since 2010. (Heikkilä et al. 2013)

Heikkilä et al (2010) have performed a calibration for a stop & go scanning system developed in Finland for the geometric surface measurement tasks of existing roads. When using 20 m vehicle stopping intervals, the accuracy of the measurement was –1 mm ± 8 mm (average, standard deviation), and with 30 m intervals – 3 m ± 9 mm. (Heikkilä et al. 2013)

Heikkilä and Marttinen (2013) have studied absolute method for using of controlling milling machines and asphalt pavers during years 2011 – 2012 in the Infra FINBIM research work packet. The final accuracy of measurement of the mobile scanning method after the optimization process was + 0,002 m (average), 0,004 m (standard deviation), -0,0012 m (minimum) and +0,005 m (maximum). It was also recommended to use at least 100 m spacing for the reference points when using mobile laser scanning for that kind of purposes. Those developments were successful, but still letting question remain: would there be more simple and more suitable way in highway maintenance field to control milling machine and asphalt paver than absolute 3-D method? That was a starting point for the research of relative method.

1.2 Objectives

Objective of the research was to define and test a relative measurement and information modelling based optimization method for asphalt pavement renovation.

2 Method

The Maintenance BIM research has been done in a part of PRE InfraFINBIM work packet. A focused research project of the Maintenance BIM with experiments in total five (5) pilot projects has been performed. A main idea of the new BIM based process was to utilize mobile laser scanning method for initial data acquirement, the use of novel 3-D analyse and modelling methods for point cloud processing, the use of new type optimization method for the planning of geometric and structural improvements needed for the existing uneven road surfaces, and further, through the creation of 3-D machine control models to apply the newest 3- D machine control systems for continuous 3-D control of practical construction work using milling machine and asphalt paver. (Heikkilä et al. 2013)

The main differences between the absolute and relative optimization methods are described in the Figures 1-2.

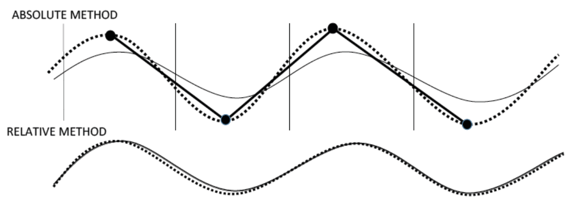

Fig. 1. Absolute and relative measurement principles used. In the absolute method, signal reference points with suitable intervals are trough linear adjustment used to improve the final accuracy of 3D point cloud. In the relative method, no signal reference points are used.

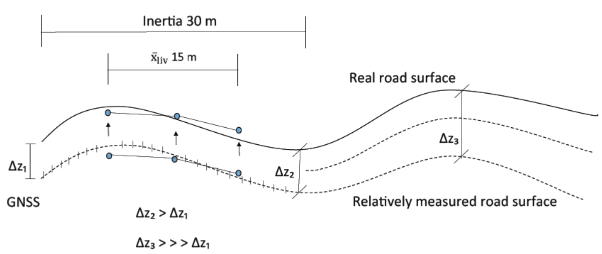

Fig. 2. In the relative method, moving average points with 15 m range and 1 m intervals are to be calculated. These points create a new relative surface that has the key information about the local unevenness of road, which can further be used, through design and construction, to the geometric improvements of the asphalt surface. At the machine control phase, the machine control can be done using the real available road surface on-site as an absolute reference surface.

Two different road parts (Vt6, Kt55) were used for the experiments in Finland during 2013 – 2014. The Roads Vt6 is first class main road from the capital Helsinki to east. It is an important highway for transportation between Finland and Russia. The two test areas of Vt6 were located between cities of Porvoo and Kouvola. Total 38 kilometres were measured in June 2013 using GEOVAP, spol. s r. o. mobile mapping (LYNX Mobile Mapper) vehicle (Fig 1.). After the measurements the survey results were analyzed and modelled using TerraScan and TerraMatch software and tools provided by Terrasolid Oy, and the design optimization was done using Road Doctor program provided by Roadscanners Oy. In the asphalt pavement machine, machine own 2-D automatic control system was used, with help of 3-D guiding machine control system provided by Roadscanners Oy. Work was started in 2013 co-operating with NCC Roads Oy and Road Administrator organization of Kaakkois-Suomen ELY-keskus near city of Kouvola, and it was continued near city of Porvoo with Road Administrator organization of Uudenmaan ELY-keskus, using the design made in 2013 in 2014 tendering competition and contract papers. NCC Roads was selected to be a contractor also in 2014. Total length of paved road was 13 kilometres in September 2013 and 10 kilometre in May 2014.

Fig. 3. GEOVAP, spol. s r. o. mobile mapping (LYNX Mobile Mapper) vehicle (Geovap).

The Road Kt55 is a second class highway in capital Helsinki region. One test area of Kt55 was located between cities of Porvoo and Mäntsälä. Total 4 kilometres were measured in May 2014 using Trimble

MX8 mobile mapping vehicle (Fig. 4). After that the survey results were analysed and modelled using the software and tools provided by Terrasolid Oy (TerraScan, TerraMatch), and design optimization was done using programs provided by Bentley (InRoads, Microstation). In milling machine, machine own 2-D automatic control system was used, with guiding of painted marks on surface of road, coming from 3-D design. Milling and was done in October 2014 by NCC Roads Oy.

Fig. 4. Trimble MX8 mobile mapping vehicle (Geotrim Oy)

3 Results

In Vt6, with relative accurate point cloud, it was possible to create 10 x 10 centimetre grid, by calculating the mean value of all points inside the grid. Those mean values were used to create 3-D break lines (Fig. 5) in edge of all lines of road. In those 3-D break lines, it was possible to create optimized lines, calculating floating mean value for 15 meter. After that the difference between 3-D break lines and optimized lines were observed. All unevenness that were greater than 2 cm in length of 15 meter, were filled with asphalt mass before paving the whole road.

Fig. 5. Placing of 3-D break lines in Vt6 (Roadscanners Oy).

In the paving contract 2013 in Vt6 Kaakkois-Suomen ELY-keskus was assuming that total amount of asphalt mass used to fix those unevenness spot before paving would be 2800 tons (mean value for total paving area 15 kg/m2). After 3-D design and using of 3-D guiding machine control system total amount of asphalt mass used to fix unevenness was 860 tons (mean value for total paving area 5 kg/m2). The saving of asphalt mass used was remarkable: near 2000 tons (mean value for total paving area 10 kg/m2) and over 70 %. In the table 1 it is shown the result of improvements of unevenness and rutness. From that table it can be concluded that places to made improvements were selected correctly (higher IRI and RUT value than reference places) and improvements where successful (good IRI value after paving).

Table 1. Vt6 Kaakkois-Suomen ELY-keskus, analyse of IRI and RUT, paving 2013.

	length (m)	IRI 4 (mm/m) (10m ave)			IRI (mm/m) (10m ave)			RUT (mm) (10m ave)		
		befor pav.	after pav.	diff.	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.
D optimized spots	2 740	1,40	0,85	0,55	2,36	1,40	0,96	6,61	1,50	5,10
‹ed spots without 3-D ›timized (reference)	5 171	1,20	0,95	0,25	1,93	1,32	0,61	4,59	1,48	3,11
ıly SMA16 100 kg/m2 eference)	5 101	1,17	0,83	0,33	1,83	1,16	0,67	4,13	1,69	2,44
›tal paving area	13 012	1,20	0,86	0,34	1,91	1,23	0,67	4,47	1,61	2,85

In paving contract 2014 in Vt6 Uudenmaan ELY-keskus total amount of asphalt mass used to fix unevenness was 33 % higher than in design (mean value for total paving area in design 15 kg/m2 and 20 kg/m2 in site used), but still less lower than what it would be without 3-D design: because of amount of unevenness length in Uudenmaan ELY-keskus was 34 % of total length and unevenness length in Kaakkois-Suomen ELY-keskus was only 21 % of total length, assumption was that mean value of using asphalt mass for fixing unevenness spots for total paving area would be 25 kg/m2. So saving in asphalt mass used to fix unevenness was 20 %. In the table 2 it is shown the result of improvements of unevenness and rutness. From that table it can be concluded that places to made improvements were selected correctly (higher IRI and RUT value than reference places) and improvements where successful (good IRI value after paving).

Table 2. Vt6 Uudenmaa ELY-keskus, analyse of IRI and RUT, paving 2014.

	length (m)	IRI 4 (mm/m) (10m ave)			IRI (mm/m) (10m ave)			RUT (mm) (10m ave)		
		befor pav.	after pav.	diff.	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.
3-D optimized spots	3 290	1,28	0,85	0,43	2,22	1,40	0,82	5,70	1,58	4,12
only SMA16 100 kg/m2 (reference)	6 365	0,88	0,77	0,12	1,60	1,16	0,44	3,84	1,42	2,42
Total paving area	9 655	1,17	0,87	0,30	2,07	1,39	0,68	5,17	1,63	3,55

The paving was made in Vt6 both years by NCC Roads Oy using 3-D guiding machine control system, where operator of paving machine was operating the machine by him selves, and having notes how to do the work coming from 3-D system (Fig. 5 and Fig. 6)

Figure 6. Paving machine operator in work with 3-D guiding machine control system (Roadscanners Oy).

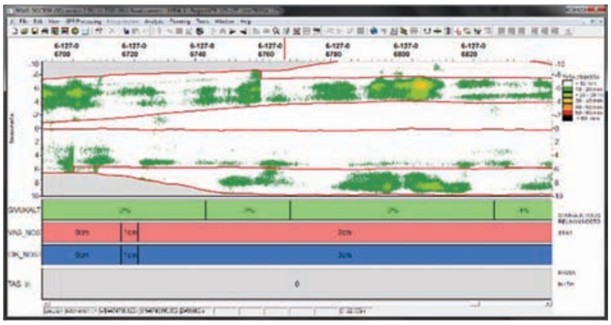

Figure 7. View in Road Doctor program 3-D guiding machine control system in asphalt paver (Roadscanners Oy).

In Niemi Kt55 research (2015), using relative accurate point cloud, Finnmap Infra developed Excel calculating sheet using VBA code to find unevenness spot in lanes. For that purpose they used point cloud with density one point per meter within length of road and five points in meter within cross-section of road. In Excel sheet road slope was calculated using floating mean value for 10 meter, and cross-slope by adding regression line in every one meters in cross-section. After that, using those calculated mean values, rate of chance values of road slope and cross-slope were analysed (Fig. 8).

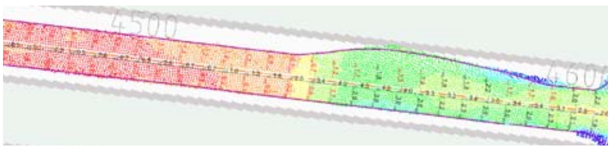

Figure 8. Total slope (road slope and cross-slope together) of road is showed using different colors (Finnmap Infra Oy).

Milling was successfully made in Kt55 using milling machine own 2-D automatic and 3-D guiding machine control system, where notes were painted to surface of road (Fig. 9). Milling depth was crosschecked by measurer every five meters in center line of road. Milled depth correlated exactly with design. Amount of milled asphalt was designed 35 330 m2 and 1 481 m3, and measured 37 082 m2 and 1 400 m3 (3 500 ton). In table 3 is shown the results of improvements of unevenness and rutness. From the table, it is easy to see, that improvements where successful (good IRI value after paving). In table 4 is shown the results of improvements of cross-slope in 200 m section having problem with water getting off the road. In that table can easily find that those spots, that had problem with cross-slopes, had also very high rut-values.

Table 3. Kt55 Uudenmaa ELY-keskus, analyse of IRI and RUT, paving 2014.

		IRI 4 (mm/m) (10m ave)			IRI (mm/m) (10m ave)			RUT (mm) (10m ave)		
	length (m)	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.
3-D optimized spots	3 675		0,78		1,86	1,41	0,45	8,11	2,42	5,69

Table 4. Kt55 Uudenmaa ELY-keskus, analyse of cross-slope, paving 2014.

	CROSS-SLOPE (%) (10m ave)			IRI (mm/m) (10m ave)			RUT (mm) (10m ave)		
distance (m)	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.	befor pav.	after pav.	diff.
1840	-2,7	-2,8	0,1	1,56	1,67	-0,11	8,49	2,1	6,4
1850	-2,9	-3,0	0,1	2,01	2,28	-0,27	10,20	2,3	7,9
1860	-1,8	-3,1	1,3	2,34	1,69	0,65	9,30	2,0	7,3
1870	-1,8	-3,2	1,4	2,10	1,23	0,87	6,63	2,6	4,0
1880	-1,1	-2,9	1,8	1,72	1,36	0,36	7,78	3,2	4,6
1890	0,0	-2,6	2,6	1,71	1,19	0,52	6,68	2,1	4,6
1900	-0,1	-2,5	2,4	1,31	1,33	-0,02	7,07	2,7	4,4
1910	-0,5	-2,6	2,1	1,36	2,08	-0,72	2,09	3,1	-1,0
1920	-1,3	-2,9	1,6	1,91	1,58	0,33	6,61	2,3	4,3
1930	-1,5	-3,0	1,5	1,85	0,64	1,21	12,46	2,6	9,9
1940	-0,6	-3,0	2,4	1,97	0,68	1,29	13,49	3,5	10,0
1950	0,0	-2,8	2,8	1,78	0,87	0,91	12,61	3,2	9,4
1960	-0,3	-2,7	2,4	2,77	1,39	1,38	12,61	3,0	9,6
1970	-0,1	-2,8	2,7	1,21	1,40	-0,19	14,00	2,8	11,2
1980	-0,3	-2,4	2,1	1,97	1,47	0,50	11,33	2,7	8,6
1990	-0,4	-2,7	2,3	1,24	0,74	0,50	11,87	3,0	8,9
2000	0,0	-2,6	2,6	1,40	1,55	-0,15	11,05	2,7	8,3
2010	0,9	-2,4	3,3	1,65	0,88	0,77	12,72	1,9	10,8
2020	0,6	-2,6	3,2	2,32	1,02	1,30	14,71	2,4	12,3
2030	-0,7	-2,7	2,0	2,64	5,08	-2,44	12,74	2,2	10,5

Figure 9. 3-D guiding machine control notes painted in surface of road (green = position in length of road (m);

red = milling depth (mm); white = milling cross-slope (%)) (Finnmap Infra Oy).

Figure 10. NCC Roads Oy, Milling machine own 2-D automatic (Finnmap Infra Oy).

3-D guiding machine control system where notes were painted (Fig. 10) to road, was easier to follow than 3-D design shown using Pad device in site. In construction field people are used to follow marks that real exist in site.

In both road parts (Vt6, Kt55), communication had very important role. Compering to tradition way to share information between owner–designer–contractor – where information is typically going only one way, and no feedback is happening – in these pilot projects, with new issues people where working, was better discussion enabled between different parts. Better way to co-operate, share information and handle whole information management in project – starting from pre information, leading to site via design – left many open questions within tradition way to work:

- what is accuracy of pre information data
- who has measured pre information data and for what purpose
- is all necessary meta information followed during whole lifecycle of information
- what infra owner really wants from designer – can he tell that
- are all documents in use latest version available – how version handling should be done
- is all information shared to those who need it
- does any feedback happens?

4 Conclusions

The test results of the relative optimization method from the both road parts (Vt6, Kt55) were successful. Material savings in relative method were remarkable compared to the traditional method: for example in Vt6 2013 material savings were 70% in asphalt material used to fixed unevenness spots. Because no signal measurements were needed in the relative method, costs were much lower compared to the absolute method: saving were in measurements costs 50%, in design costs 25% and in construction costs 10%. Maintenance design needed was completed only using relative coordinates. Production models made by designer were possible to follow in sites, but ways to give the 3-D guiding machine control system notes to work group should be studied more. Possibilities to develop 3-D guiding machine control interfaces are great. For example the design could be shown to workers using augmented reality in devices like pads or virtual glasses. That would make design easier to follow in site while moving (Fig. 11). The relative method does not apply to the road parts, where absolute geometry dependences are critical.

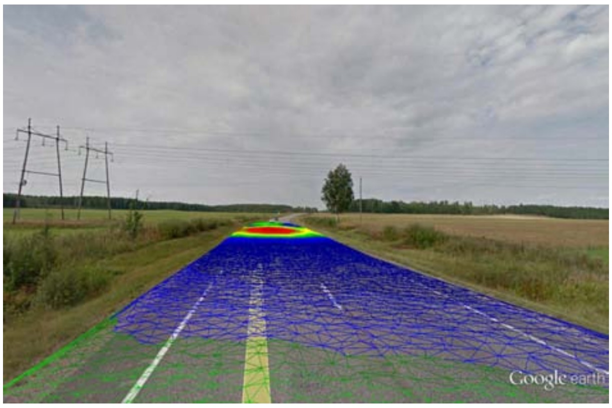

Figure 11. Design view true Google Earth in Pad device with added reality (Finnmap Infra Oy).

In road network, the maintenance information management should be more research and develop to that level what technical solutions makes already possible. Traditional system, where people dealing with only part of information available, is not the best way. Information should be shared with every parts dealing with projects. New digital interfaces to share information should be studied by doing benchmarking to systems that are used in different countries.

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