The evolution of a mountain road network from the original war-use to the forest one and its current management

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Abstract:
In some mountain areas located in Northeast Italy the present forest road network has been partially developed using the previous military road network built during the First World War (1st WW). The current management of the forest areas considers road network essential to provide access for the forest operations but also to increase the value of recreation activities and historical tourism regarding the heritage value of the areas.
The aim of the study was to investigate the technical evolution of a mountainous road network for forest operation and forest activities from the beginning of the last century to present. The research consisted of preliminary reconnaissance of the original road network using the 1st WW military maps, a further reconnaissance using the technical maps dated to the 60's of the last century and the survey of the current road network through GPS.
Furthermore the study aimed to evaluate the current condition of the original road network according to its current use in order to highlight the influence between the building standards of the roads and the evolution in terms of transportation system and traffic management.

Keywords: road networks, mountainous areas, historical road, 1st WW

1 Introduction

During the First World War (1st WW) period most of the front between Italian and Austro-Hungarian Armies lay on the Alpine areas. Due to the lack of transportation infrastructures both the Armies were forced to design and build a wide road network necessary for troops displacement and material supply (only on the really steep areas cableway systems were used). The technical features and the material used to build such a road network (Figure 1) were so well fit that most of the roads are still present (Figure 2) and they are used mainly as forest road network.

Figure 1: Italian soldiers gravelling a new built military road

Figure 2: Present condition of a well preserved military road

The purpose of this study is to investigate the improvement of the transport network from the beginning of the 1st WW to the existing road network within a mountainous forest area and to evaluate the condition of the original transport network according to its re-engineered condition and its current use.

2 Material and Methods

2.1 Study area

Study areas are located in the Altopiano dei Sette Comuni in the North-eastern part of Italy. It represents a meaningful case study for the analysis of the expansion of the transport network from the 1st WW to the current forest road network (Cavalli et al. 2010). Two forest areas were identified, differing mainly by the average slope gradient of the terrain and with the same extent of forest area and almost the same area managed through Forest Management Plans (Table 1).

Table 1: Main characteristics of the two study areas (A: area, FA: incidence of the forest area; MF: managed forest; MT: main tree species)

Study area	A	FA	MF	MT	Slope gradient	
	ha	%	%	-	% (mean)	% (St.Dev)
Verena	5776	86.7	80.8	Spruce and fir	40.3	14.26
Boscon	3372	86.8	86.8	Spruce and beech	28.8	31.37

The Italian Army at the beginning of the 1st WW controlled both the areas. In the Verena area were located two important Italian fortresses and the transport network was designed mainly to provide logistic access to this places. Boscon area remains under Italian possession during all the 1st WW while Verena area was occupied by Austro-Hungarian Army from May 1916 until the end of the war and during this period transport network was improved.

2.2 Current extension of the road network

In the areas, the road network differs greatly due to its development through time and layout over terrain. The geographic patterns of roads in forest landscapes can differ substantially from place to place, with commensurate differences in operational level. Nevertheless, the awareness of the extension of the forest road network, by excluding road with dominant public use, is deficient in technical descriptions. For these reasons between 2010 and 2011 the forest road network of the two areas was surveyed using a professional GPS (Trimble Pathfinder ProXH). Therefore each road segment was classified according to its main use (Table 2) and its operative level (Table 3).

Table 2: Road classification according to its use

Class	Function	Description
O	Ordinary roads	National and regional major roads generally not used for forest purposes
C	Access roads	Principal and roads rarely used for forest purposes
MF	Multi-function roads	Secondary roads with free access commonly used for rural, forestry or recreational purposes
FOR	Forest roads	Forest roads with free or restricted access for forestry purposes
NC	Not classified	Network of not permanent skid roads or trail not practicable with vehicles, including also recreational trails

Table 3: Road classification according to its operative level

Class	Description	Forest operations
1	Low mobility and high load capacity	Truck with trailer
2	Low mobility and medium (+) load capacity	Truck
3	High mobility and medium (-) load capacity	Forwarder or tractor with forest trailer
4	High mobility and low or null load capacity	Small tractor with single axe carriage
0	Not permanent skid roads or trail not practicable with vehicles	

2.3 Historical maps

In order to analyze the evolution of the road network in the two study areas, a first research on the availability of historical maps and aerial-photos has been carried out. To guarantee the standardization of the data, the research considered the use of historical maps with the same scale, the same revising time and the same origin. According to these remarks, 9 historical maps of the *Carta d'Italia,* upgraded during the 1st WW for military use, were collected from the Biblioteca Civica Bertoliana (Vicenza) (Table 4).

Table 4: List of the collected and georeferenced historical maps for military use

Code	Map	Scale	First survey	General Reconnaissance	Upgrade
Conco	Sheet 37 Carta d'Italia Sez. III.N.E.	1:25000	1887	1910	15.8.1917
Valstagna	Sheet 37 Carta d'Italia Sez. IV.S.E.	1:25000	1886	1910	15.8.1917
Asiago	Sheet 37 Carta d'Italia Sez. IV S.O.	1:25000	1886	-	-
Monte Lisser	Sheet 37 Carta d'Italia Sez. IV N.E.	1:25000	1886	-	15.8.1917
Cima Dodici	Sheet 37 Carta d'Italia Sez. IV N.O.	1:25000	-	1910	15.8.1917
Monte Verena	Sheet 36 Carta d'Italia Sez I. N.E .	1:25000	-	-	15.8.1917
Rotzo	Sheet 36 Carta d'Italia Sez I. S.E.	1:25000	1886	1912	15.8.1917
Caltrano	Sheet 36 Carta d'Italia Sez III. N.O.	1:25000	1887	-	15.8.1917
Arsiero	Sheet 36 Carta d'Italia Sez II. N.E.	1:25000	1886	1912	31.5.1917

The collected maps reported a considerable numbers of geographic features and in particular a good and detailed description of features concerning the transport network. Roads are categorized in 4 main operative classes; furthermore permanent trails adapted to haulage by mules (*mulattiera*) are reported.

Table 5: Transport network classification of the Carta d'Italia for military use

Class	Width	Slope	Other features
	m	%	
1	> 8	< 7; 7 - 12; > 12	Wall; bottlenecks and extra width
2	6 - 8	< 7; 7 - 12; > 12	Wall; bottlenecks and extra width
3	< 6	< 7; 7 - 12; > 12	Wall; bottlenecks and extra width
4	Not indicated	Not specified	Wall; bottlenecks and extra width
Mulattiera	Not indicated	Not specified	Not specified

A simple explanatory categorization of the road transportation network during the 1st WW in similar mountainous condition to the ones of Altopiano dei Sette Comuni is reported by Sigurtà (2002) which indicates *camionabili* as truck roads, generally with a width > 4.0 m and a gradient < 10% and the *carrozzabili* as road adapted for tractor with carriage, with a width between 2.50 and 4.0 m and a gradient < 10%. The same Author also reports the descriptions of the *mulattiera* which is characterized by a width variable between 1.5 to 2.5 m and a gradient higher than 10% (maximum 28-30%). Boglione (2008) reports that in mountainous area, the *camionabili* and *carrozzabili* roads can be characterized for short section also by a gradient higher than 10% (maximum of 12-14%). The digital images (.tiff) of the maps were obtained by scanning the maps. The scanned maps were thus aligned and georeferenced in WGS 84 UTM 32 N and then grouped in a single dataset.

In order to verify the condition of the forest road network at an intermediate state, historical aerial-photos of the Italian Aeronautic Group (GAI) dated 1954-55 (AA.VV., 2011) were collected and grouped in a single datataset. The GAI aerial-photos were scanned at 600 dpi resolution to be adapted to an application scale of 1:10000 (Savio, 2011).

The two dataset concerning the maps of the *Carta d'Italia* for military use and the GAI aerial-photos were therefore integrated in a single geodatabase (Figure 3).

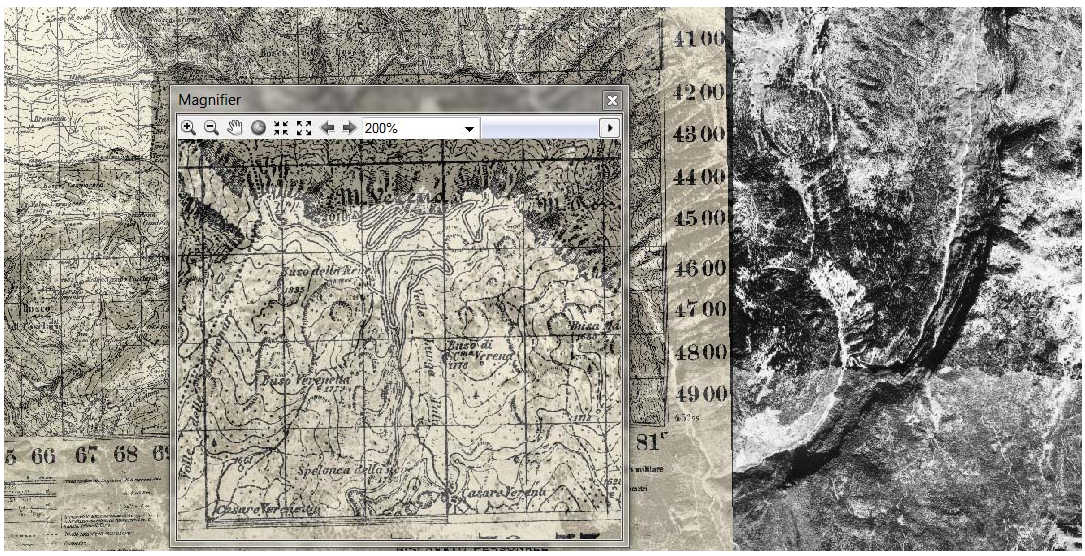

Figure 3: Historical source geodatabase with a map of the Carta d'Italia and GAI aerial-photos

2.4 Extraction of the historical transport network

The transport network on the 1917 historical maps was digitalized in vector format. For each transport network segment reported in the maps, the class, the width, the gradient and the presence of walls, bottlenecks and extra widths (as landings, switchback area and square) were reported.

On a first step the digitalization considered the same layout shown by the maps. Because the maps were not always reliable concerning the layout of the transport segments, a second step considered the alignment of the digitalized segment to the current road network previously surveyed by GPS.

The alignment considered integration of the information of the historical road network to the current road network. The integration was evaluated only where the segments in the maps clearly overlapped (within a buffer of 30 m) the segment surveyed by GPS. Where the historical road network was different, the road network was not integrated to the dataset of the current road network.

The forest road network shown in the GAI aerial-photos was digitalized and therefore integrated to the current road network. The final geodatabase of the current road network specified for each segment its existence in the three considered periods (1915-1918, 1953-1954, 2010-2011).

All the GIS operations, dataset management and analyses were supported by ArcGIS 10 (ESRI, 2010a), while the statistical analyses were sorted out by SPSS 18 (2010).

2.5 Field surveys plan

A part of the analysis attempted to survey current road segments overlapping the historical transportation network back to the 1st WW. The surveys were conducted by using a professional GPS with a resolution approximately to 1 m (Trimble Pathfinder ProXH).

The main investigated features were the deterioration of the artifacts (Figure 4) and the re-engineered condition of the historical transportation network (Figure 5).

Figure 4: Evaluation on the deterioration of retaining walls

Figure 5: A *mulattiera* partially re-engineered

The survey procedure considered to collect qualitative and quantitative features and parameters by a dedicated format developed in ArcPAD 8 (ESRI, 2010b).

The surveys were conducted in order to cover all the road classes included in the legend of the historical *Carta d'Italia*. The survey plan was previously randomly extracted with the support of the GIS analysis. The field procedure considered the collection of different parameters and information within segments of 25 m length.

The following attributes were thus verified for each road segment:

- Width: the current average carriageway (m)
- Gradient: the current gradient (%)
- Current condition compared to the 1st WW one: completely re-engineered, partially re-engineered, partially preserved, completely preserved
- Historical artifacts: retaining walls, drainage systems (such as camber, culverts, ditches or cross drain) and bridges
- Historical artifact deterioration: high, medium, low, not valuable
- Road surface: current road surface (asphalt, gravel or natural)
- Current access: reporting the road traffic limitation and use

3 Results and Discussions

3.1 The road network from the 1st WW to nowadays

The data obtained from the digitalization of the historical maps of the 1st WW and from the digitalization of the GAI aerial-photos indicated a considerable increment (+126%) of the extension of the road network from the 1st WW to nowadays (Table 6).

Table 6: The road network extension between 1st WW to 2010-2011

	1st WW	1953-1954		2010-2011		
Area	**A**	**B**	**Δ AB**	**C**	**Δ BC**	**Δ AC**
	km	**km**	**%**	**km**	**%**	**%**
Verena	69.8	105.9	+51.7	155.4	+46.7	+122.6
Boscon	44.1	90.6	+105.5	102.2	+12.8	+131.7
Total	113.9	196.5	+72.5	257.6	+31.1	+126.2

The Class 3 and Class 4 road network of the 1st WW were included here as the legend of the *Carta d'Italia* detailed them useable for vehicles, while *mulattiera* was not considered in this calculation.

By comparing the road network extension (including forested and not forested area) between the 1st WW to the nowadays, the Verena area increased the road network density from 12.1 m ha^{-1} to 26.9 m ha^{-1}, while the Boscon area increased the road network from 13.1 m ha^{-1} to 30.3 m ha^{-1}.

Table 7 reports the current road network extension according to the operative level classification, whereas Table 8 shows the 1st WW road network extension according to the operative classification as indicated in the legend of the *Carta d'Italia*.

Table 7: Operative level of the current road network according to Table 3

Operative level	Boscon			Verena		
Class	km	%	m ha^{-1}	km	%	m ha^{-1}
1	7.3	7.1	2.2	12.8	8.2	2.2
2	42.1	41.2	12.5	26.2	16.9	4.5
3	31.0	30.4	9.2	67.2	43.3	11.6
4	21.8	21.4	6.5	49.2	31.7	8.5
Total	102.2	100	30.3	155.4	100	26.9

Table 8: Operative level of the 1st WW transport network according to Table 5

Operative level	Boscon			Verena		
Class	km	%	m ha^{-1}	km	%	m ha^{-1}
3	35.1	51.0	10.4	39.5	32.6	6.8
4	9.0	13.1	2.7	30.3	25.0	5.2
mulattiera	24.7	35.9	7.3	51.3	42.4	8.9
Total	68.8	100	20.4	121.1	100	21.0

3.2 The original alignment of the 1st WW transport network

As detailed in Table 8, the 1st WW road network in the study areas was composed by Class 3, Class 4 and *mulattiera*. According to the legend of the *Carta d'Italia*, it is evident that the roads were characterized generally by a width smaller than 6 m (including shoulders and carriageway) and the *mulattiera* was a considerable part of the 1st WW transportation network. This condition may be reasonable comparable to the condition of the military road network in mountain areas described by Boglione (2008) in the North-western part of Italy and by Sigurtà (2002) in the North-central part of Italy.

The analysis verified the location of the transportation network according to the terrain characteristic surrounding each transport segments (a buffer of 50 m was considered for both the side of the road segment). The analysis considered the terrain steepness (or terrain gradient) in percentage. The terrain gradient was calculated by a Digital Terrain Model with a resolution of 10 m x 10 m. At this resolution the morphology of the terrain was considered constant between the 1st WW and nowadays situation. Based on this approach, the results highlighted that in the Verena area the 1st WW transportation network (135 segments with an average steepness of the surrounding terrain of 30.95%) was located in terrain steeper than in the Boscon area (102 segments with an average steepness of the surrounding terrain of 22.17%). The two means was thus compared by the non-parametric test of Mann-Whitney with the null hypothesis that the two means were equal. The result reported a ρ-value = 0.000 justifying the rejection of the null hypothesis. Therefore a total of 214 segments were extracted and analyzed in term of gradient. The gradient was determined by considering the rise between the start and the end vertex of each segment and the length of the same segment. The procedure was based on a semiautomatic method developed in ArcGIS 10. Data obtained on the gradient of each transportation network segment highlighted an average gradient of 5.93% for the Boscon area and of 8.62% for the Verena area. The Independent-Samples T Test procedure was applied to test the significance of the difference between the two means with a confidence interval of 95%. The T-test reported a ρ-value = 0.000, justifying the rejection of the null hypothesis that the two means were equal.

Next the One-Way ANOVA procedure let to compare the means of the gradient for the three groups: Class 3, Class 4 and *mulattiera*. As the Levene statistic test confirmed the null hypothesis that the group variances were equal, the pairwise multiple comparisons was based on the Least Significant Difference (LSD) test. The highlights of the statistical analysis are reported on Table 9.

Table 9: LSD test on the means of the gradient for the three historical transportation classes (*the mean difference is significant at the 0.05 level)

Transportation class		Mean difference (A-B)	Std.error	*p-value*	Confidence interval 95%	
A	B				Lower bound	Upper bound
Class 3	Class 4	-0.965	0.987	0.329	-2.91	0.98
	*mulattiera**	-4.259	0.812	0.000	-5.86	-2.66
Class 4	Class 3	0.965	0.987	0.329	-0.98	2.91
	*mulattiera**	-3.294	1.013	0.001	-5.29	-1.30
mulattiera	Class 3*	4.259	0.812	0.000	2.66	5.86
	Class 4*	3.294	1.013	0.001	1.30	5.29

It can be observed that the *mulattiera* was the element of the 1st WW transportation network with the higher gradient, in average 10.0% with a maximum value of 23.8%. The road segments included in the Class 3 and Class 4 showed an average gradient of 5.75% and 6.72% with a maximum value of 18.8%.

3.3 The current alignment of the 1st WW transport network still in use

The length of the current road network overlapping the 1st WW transportation network was evaluated 80.5 km, approximately the 31.3% of the existing road network. Therefore the current alignment of the 1st WW transport network still in use as forest road network was analyzed in term of carriageways and gradient (Table 10) by considering the data collected by GPS during 2010 and 2011.

The analyzed road network was composed of 87 segments grouped according to their origin reported in the *Carta d'Italia*. The resulting means for the carriageways and the gradient are reported on Table 11.

Table 10: Extension of the 1st WW transport network still in use as forest road network

Operative level	Verena			Boscon		
Class	km	%	m ha^{-1}	km	%	m ha^{-1}
3	25.4	62.1	7.5	19.5	49.0	3.4
4	6.3	15.5	1.9	16.3	41.2	2.8
mulattiera	9.1	22.4	2.7	3.9	9.8	0.7
Total	40.8	100	12.1	39.7	100	6.9

Table 11: Descriptive statistic for the carriageway and gradient of the 1st WW transport network still in use as forest road network

Variable	Group	n°	Mean	Std.Dev.	Std.Error	Confidence interval 95%		Min.	Max.
						Lower bound	Lower bound		
CW (m)	Class 3	46	3.6	0.660	0.097	3.4	3.8	2.5	5.0
	Class 4	22	2.8	0.527	0.112	2.6	3.0	2.0	4.0
	mulattiera	19	3.1	0.762	0.175	2.7	3.4	2.0	4.0
	all	87	3.3	0.746	0.080	3.1	3.5	2.0	5.0
VG (%)	Class 3	46	4.3	3.300	0.487	3.3	5.3	0.0	10.3
	Class 4	22	5.2	3.540	0.755	3.6	6.8	0.0	10.3
	mulattiera	19	6.6	5.450	1.250	4.0	9.2	0.0	16.2
	all	87	5.0	3.974	0.426	4.2	5.9	0.0	16.2

The One-Way ANOVA was used to compare the means of the carriageway and the gradient between the three groups Class 3, Class 4 and *mulattiera*. The pairwise multiple comparisons was based on the Least Significant Difference (LSD) test for the evaluation of the means of carriageway, as the Levene statistic test confirmed the null hypothesis that the variances of the three group were equal (Table 12). For the gradient the Levene statistic test did not confirms the null hypothesis that the group variances were equal and for this reason the Tamhane T2 test was applied (Table 13).

Table 12: LSD test on the means of the carriageway (CW) (*: the mean difference is significant at the 0.05 level)

Group (Class)		Mean difference (A-B)	Std.error	*p-value*	Confidence interval 95%	
A	B				Lower bound	Upper bound
Class 3	Class 4*	0.842	0.170	0.000	0.504	1.179
	*mulattiera**	0.584	0.178	0.002	0.230	0.939
Class 4	Class 3*	-0.842	0.170	0.000	-1.179	-0.504
	mulattiera	-0.257	0.205	0.213	-0.664	0.150
mulattiera	Class 3*	-0.584	0.178	0.002	-0.939	-0.230
	Class 4	0.257	0.205	0.213	-0.150	0.664

Table 13: Tamhane T2 test on the means of the carriageway (CW) (*: the mean difference is significant at the 0.05 level)

Group (Class)		Mean difference (A-B)	Std.error	*p-value*	Confidence interval 95%	
A	B				Lower bound	Upper bound
Class 3	Class 4	-0.875	0.898	0.707	-3.115	1.366
	mulattiera	-2.270	1.342	0.280	-5.717	1.177
Class 4	Class 3	0.875	0.898	0.707	-1.366	3.115
	mulattiera	-1.395	1.461	0.722	-5.088	2.297
mulattiera	Class 3	2.270	1.342	0.280	-1.177	5.717
	Class 4	1.395	1.461	0.722	-2.297	5.088

As it can be seen from Table 12, the Class 3 reported a significantly larger carriageways than Class 4 and *mulattiera*; alternatively the statistical analysis indicated that the means of the carriageways of Class 4 and *mulattiera* are equal.

As it is indicated on Table 13, the means of the gradient of all the groups are equal. For what it concerns the *mulattiera*, it could suggested that only the *mulattiera* that have been re-designed with a gradient suitable to the traffic of vehicles are nowadays part of the road networks.

3.4 Evaluation on the remaining artifacts of the historical transportation network

The evaluation of the current state of the 1st WW transportation network was determined through a survey of 145 control points along the current road network. The 36% of the control points was collected on roads originally 1st WW Class 3, 48% on roads 1st WW Class 4 and the remaining 16% on *mulattiera*.

The results highlight (Table 14) that a great number of road segments originally classified as Class 3 are currently adapted to vehicles with low mobility and high load capacity (corresponding to the Class 1 and Class 2 in the current operational classification reported on Table 3). The results also highlight as the *mulattiera* has been often re-engineered to the current operational Class 2 and Class 3, while the road segment originally classified as Class 4 have been adapted to an high mobility and medium low load capacity or to an high mobility and a low or null load capacity (corresponding to the Class 3 and Class 4 in the current operational classification reported on Table 3).

Table 14: Current operational classification of the 1st WW transportation network

1st WW operational classification *(see Table 4)*	Current operational classification *(see Table 3)*			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Class 3	7.7%	55.8%	32.7%	3.8%
Class 4	-	10.0%	67.1%	22.9%
mulattiera	-	56.5%	43.5%	-

As shown in Figure 3, *mulattiera* have been substantially completely re-engineered in their horizontal and gradient alignment. The degradation of the historical artifacts, when they could be still valuated, was appreciable high for the *mulattiera* and for the Class 3 (Figure 4).

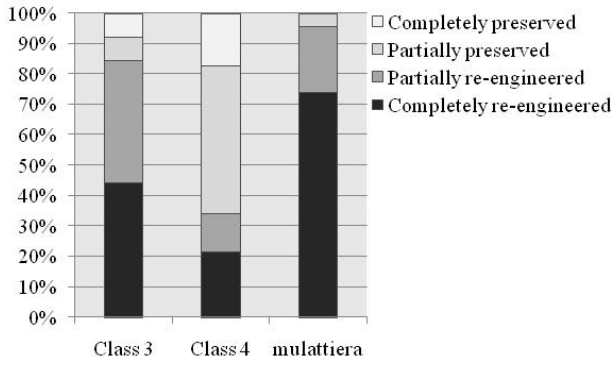

Figure 3: Upgrading of the historical transportation network according to the transportation classes reported in the *Carta d'Italia*

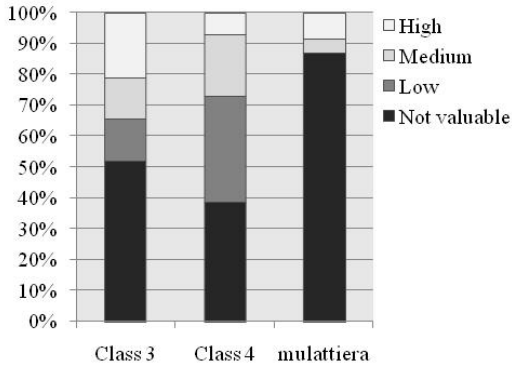

Figure 4: Deterioration of the alignment and artifacts of the 1st WW transportation network

Furthermore the current roads closed to the ordinary traffic (forest roads) are the most preserved in term of the original alignment and artifacts, while the current roads opened to the ordinary traffic (public roads) are the most upgraded and re-engineered in respect to their origin (Figure 5). For both the group it seem that barely the 50% of the artifacts shows a high or medium deterioration.

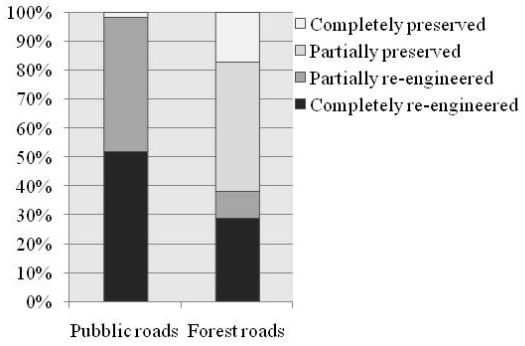

Figure 5: Upgrading of the 1st WW transportation network according to current traffic limitation

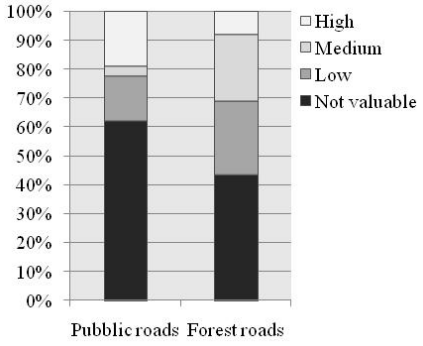

Figure 6: Deterioration of the alignment and artifacts in relation to the traffic limitation

4 Conclusions

The purpose of this study was to investigate the improvement of the transport network from the beginning of the 1st WW to the existing road network within mountainous forest areas.

The first results for the two areas selected in the Altopiano di Asiago confirmed that an appreciable part of the original 1st WW transportation network is still in use. Part of the network has been totally re-engineered in order to support an ordinary traffic related to agriculture and forest activities and nowadays also for the summer and winter recreational activities. Part of the network has been remained partially preserved because only used for forestry or stone extraction purposes.

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