The influence of management and construction methods in the repair costs of Spain's low-volume road network

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Abstract

This paper describes the entire process of the implementation of the Spanish low volume road network, including the design criteria, the construction techniques and the management policies during all the periods. The current situation of low volume roads in Spain was analysed with respect to the legal framework and their actual condition. In addition, the budget required for the repair of 41 low volume roads throughout Spain was calculated in order to statistically analyse the influence of the pavement materials and the period of construction. The main conclusions were that low volume roads constructed during the 1970's are currently those in the best state of repair and those requiring the lower repair costs, even lower than those constructed after 1980's. In addition, low volume roads constructed with higher quality materials and using standardised techniques required five times lower repair costs than those made of lower quality materials.

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Introduction

Low-volume roads played a vital role in the development of Spanish agriculture over the twentieth century. At the beginning of that century the Spanish economy was based on agriculture that had experienced little social or economic development (Simpson, 1995). Parcels of agricultural land were cultivated with practically no mechanisation at all, mainly based on human labour forces and working animals. Productivity was very low, and living conditions in rural areas were poor and uncomfortable. However, the economic structure of Spain changed drastically within twenty years, moving the country towards an economy more strongly based on industry and services. In 1900 some 60.4% of the active population was employed in agriculture, while in 1930 this had fallen to 46.1%, a figure that remained largely stable until the beginning of the 1960s. The profound transformation of agriculture seen during that decade (Simpson, 1995) is manifested today in that just 5.8% of the population is now involved in this sector, which contributes just 2.5% to the country's gross domestic product.

The political tensions appeared during the Second Republic (1936-1939) led to the abandonment of the modernisation plans and, thus, the construction of low volume roads was abandoned. Moreover, much of the agricultural machinery and infrastructures were destroyed during the Civil War. After the conflict, the Franco regime (1939-1975) tried to modernise the country. However, the autarchy of the regime imposed during the 1940s led to a lack of foreign investment, a scarcity of inputs for crop production, and the failure to acquire the earth moving machinery required for the construction of low-volume roads.

The work undertaken by many of the administrative bodies created to stimulate and modernise Spanish agriculture, such as the *Instituto Nacional de Colonización* (INC, the National Colonisation Institute) would not bear fruit until the 1950s, when the regime began to open up to the outside world. The *Servicio Nacional de Concentración Parcelaria* (SNCP; the National Land Parcel Concentration Service) also played vital roles in the improvement of the country's agriculture.

Some of the main tasks of these bodies included the mechanisation of the rural environment, increasing the use of fertiliser, and the creation of new and much more productive irrigated areas. The development of these activities required during the period 1950-1970 a rapid expansion in the low volume road network, which became an essential activity undertaken by these bodies. The State engineers and technicians soon realised that the design and construction of low volume roads would need to be substantially improved to meet the desired rate of construction, and so many went abroad to learn the techniques used in other countries.

The planning of low volume road networks had the main aim of guaranteeing access to all land that could be cultivated, irrespective of the economic profit this might bring. Certainly, the production of the network suffered, during its early stages, the difficulties typical of developing countries (Overgaard, 2004; Robinson and Thagesen, 2004). New technologies had to be used, few people were qualified to do the work required, and the experience required to properly plan multiple networks in different parts of the country was lacking. Nonetheless, rapid improvements were made in the quantity and quality of Spain's low volume roads, a success that made a significant contribution to the advances made in agricultural productivity and the living conditions of the rural population.

Unfortunately, the process of transferring ownership of the new roads to local town halls did not always have the desired effect; this led to problems that will be discussed later. Franco's death in 1975 led to the appearance of a democratic parliamentary monarchy in Spain. The nation was divided into different regions, the so-called *Comunidades Autónomas* (Autonomous Regions). These new administrative entities gradually took on responsibilities that once belonged to the State, including the management and construction of low volume roads within their geographical boundaries. This paper describes the management and planning mechanisms followed and the techniques used for implanting the Spanish network of low volume roads. Then, the paper also analyses the ownership and the finance mechanisms in force, which are a consequence of the planning of the network in most cases. Finally, the paper estimates the repair costs required to rehabilitate the network, based on data previously taken by the authors (Gallego *et al.*, 2008a, 2008b). In these works, the condition of 41 low volume roads was analysed and the tasks that should be conducted to repair them were determined. Therefore, with this information repair costs based on current prices were obtained. A special attention is paid to analyse the influence of the construction era and the pavement types on repair costs. Thus, the paper focuses on analysing the consequences on the condition and maintenance of low-volume roads derived from a central planning. Hopefully, this experience might help other countries now at a similar point in their development avoid some of the difficulties that can appear. Some recommendations are also made regarding the implantation of low volume road networks that may be of value to other countries.

This work was prepared using the information obtained by the authors during the development of a specific methodology for characterising the condition of low volume roads (Gallego *et al.*, 2008a) and its use with 41 such roads in Spain (Gallego *et al.*, 2008b).

Techniques used for the design and construction of low volume roads

Although modernisation plans existed before the Spanish Civil War took place (1936-1939), this conflict promoted their abandonment. During this period much of the agricultural machinery as well as the infrastructures were destroyed. Therefore, the construction of new low volume roads did not begin until the end of the 1940s due to the problems of trying to implant centralised bodies with authority over the entire country and the autarchy of the first years of the Franco regime. After that, it can be identified three eras, the characteristics of which are discussed later: the first from the end of the 1940s until the end of the 1960s, the second from the end of the 1960s until the end of the 1980s, and the third from the end of the 1980s until the present.

Very different techniques have been used in the design of low volume roads in Spain (Dal-Ré, 2003). In areas where irrigation plans were put into operation, networks were designed like meshes (Figure 1). In such cases the entire irrigated area was covered by low volume roads designed on the basis of the traffic they were foreseen to have to take. Thus, traffic intensity and distribution was affected by the division of the irrigation network and the typical irrigated crop rotations of that area. For these reasons, some of these low volume roads were designed as the main roads of the network, *i.e.*, to receive traffic from other roads and to provide a link with a local village or the closest main road. The majority of these irrigated lands were flat, meaning that low volume roads had to be built on embankments to avoid them being affected by the water used in the area. Traffic intensities and loads in these areas were generally higher than in rain-fed lands, so they were constructed with better quality materials.

Outside of irrigation areas, a tree-like (Figure 2) network design was used. In this case, the final objective was to provide access to any

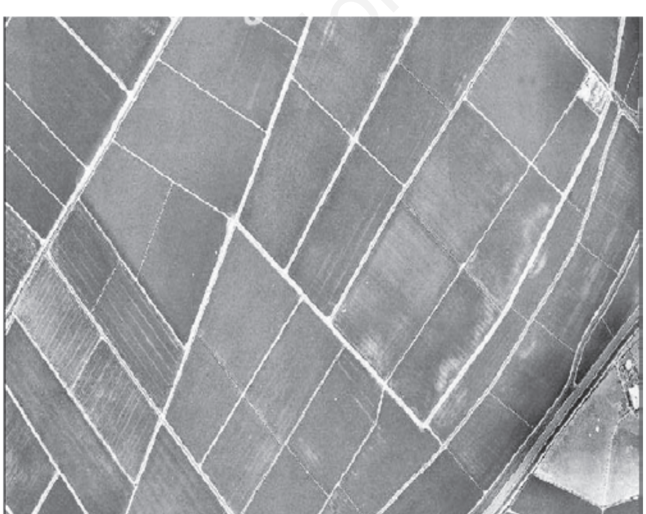

Figure 1. Low volume roads in an irrigated area of Spain. Mesh system.

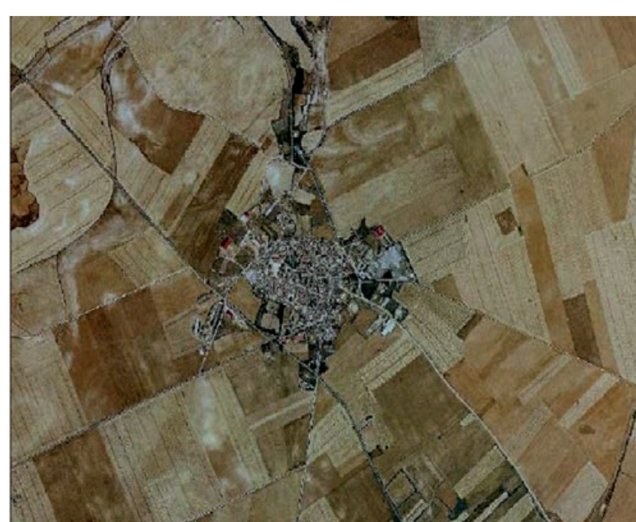

Figure 2. Low volume roads in a dry land area of Spain. Tree system.

plot within the municipality, no matter how small. The local village lay at the centre of the network, with the largest low volume roads running out from this nucleus, with secondary roads extending out from these and tertiary roads extending out from the latter. Some of the low volume roads in this design went beyond the municipality's boundaries to give access to other villages or main roads. They were therefore designed to be somewhat more comfortable to travel on than the rest of the *tree*, *i.e.*, their pavements were of better quality, more culverts were used to avoid waterlogging, and they were built in such a way that their longitudinal gradients were not so steep. In both design models, the principle roads were 8 m wide (a 6 m transit surface with a 1 m shoulder on either side). The secondary roads were usually 5-6 m across, and the tertiary roads just 3 m across (a single lane) with widenings every 300 m in some cases to allow vehicles moving in opposite directions to pass one another. All these low volume roads were provided with transverse gradients to evacuate water from their surfaces - a vital element in avoiding the deterioration of their surfaces. Sometimes ditches were provided at the edge of the road, but their use became generalised especially during the second era.

Construction techniques used during the first era

Little earth-moving equipment was available in Spain during this period (end 1940s - end 1960s), and most construction work was therefore based on large human labour forces. The lack of such equipment meant that large-scale excavations and embankment building had to be avoided, and the longitudinal slope of the roads constructed followed that of the original terrain as much as possible. In some cases advantage was taken of already existing tracks, thus keeping costs down. However, a very large number of low volume roads were built in order to allow access to the newly concentrated lands. Ditches at the sides of the road were only infrequently built, and very few culverts were used. Those that were used were usually masonry structures, further reflecting the great use of manpower.

The most common pavement used during this era consisted on a single base layer of macadam (Figure 3). This material consists of fractured stones 6-8 mm in diameter, which are later compacted and the spaces are filled with sand. If macadam was laid over a clayed substrate, then a granular subbase layer had to be laid below the macadam base. This kind of pavement is suitable for low traffic loads and its durability is good. Thus, the low volume roads built during this era remained in good condition for many years. At the end of this era the use of stabilised granular materials became more common, especially in irrigated areas.

The rudimentary conditioning of old tracks was maintained in many areas for a time despite the considerable increase in the construction of low volume roads. These unpaved tracks, which were used by carts, were conditioned annually via the pouring of crushed stones in the most deteriorated areas with no technical criteria. This practice was based on personal contributions; thus, those who could make no financial contribution were obliged to undertake the repair work. The aim of such repairs was to improve movement, even though this was often achieved by the indiscriminate use of elements with a high coefficient of friction to prevent shoving. During this first era traffic signs were not placed since it was assumed that only agricultural vehicles were going to use these roads.

Construction techniques used during the second era

During the second era (end of the 1960s - mid 1980s), the Spanish government acquired a great deal of earth-moving machinery for the construction of low volume roads. This led to a drastic fall in the need for labour and the ability to design longer roads with shallower gradients. Excavation and embankment building acquired more importance, and a much more comfortable driving became possible.

The use of macadam surfaces declined since it was difficult to get a good finish without a large workforce. Instead, stabilised granular materials began to be used for pavement construction, especially in irrigated lands of Extremadura (western Spain) and Aragón (northeast). This method was largely unknown in Spain and relatively expensive - but compared to the total cost of bringing land under irrigated agriculture the increased cost per hectare was virtually inappreciable. The trend at the time was to use two layers of granular materials: the sub base and the base, which also acted as the road surface.

During this era, knowledge regarding the techniques used for the construction of low volume roads had improved through State engineers visiting other countries and learning new construction techniques. As shown in other countries (Betz and Bauman, 2007; Van Zyl *et al.*, 2007), the construction of low volume roads improved in quality due to the increased number of studies being made into the mechanical properties of the foundation of the roads and the materials used for pavement construction.

Thus, the American Association of State and Highway Transportation Officials (AASHTO) M 43-05 sizes of aggregates were used in the construction of this kind of pavements. Larger graded aggregates (max. 5.08 mm) were used for the sub-base and smaller materials (max. 2.54 mm) for the base. Trailer-laboratories at the construction site were equipped with the necessary quality-monitoring instruments (AASHTO, 2005). Chemical stabilisation with cement had also been used beforehand in some irrigated areas, *e.g.*, the Marismas del Guadalquivir (southern Spain).

During this era great part of the low volume roads were constructed in rain-fed lands, where the profit made per hectare was much lower than in irrigated areas. The use of stabilised granular materials was therefore relatively more expensive in these areas. Alternative solutions using available local materials were therefore sought, and consequently the low volume roads made in these areas differed in quality depending on their importance within the network. Main roads were made by using the best materials. Otherwise, some secondary roads were made employing better techniques, but many secondary and all tertiary roads were constructed in a more rudimentary fashion. Indeed,

Figure 3. Low volume road paved with macadam.

sometimes they were just marked out and compacted.

Many practical difficulties arose in the beginning of implementing stabilisation techniques. One was the scant availability of sufficient water for the stabilisation process, requiring tanker lorries bring water to the site. Another was the inexperience of the technicians in charge, who were used to laying macadam, or the companies hired to do the work, which were commonly technically incapable of performing the tasks required. To solve these problems, the state engineers provided training for workers and technicians.

It was during this era that it became a generalised practice the use of ditches and culverts to evacuate water from road surfaces. Generally, standard sized *in situ*-made or prefabricated concrete or fibrocement pieces were used. Traffic signs were also installed, especially those limiting speeds and tonnage, and those that identified roads.

Construction techniques used during the third era

After the 1980s the construction of low volume roads tailed off, the focus moving to the repair of those already built. Those that were built were similar to those of the second era, but it was common to use a layer of asphalt for the road surface, something rarely laid during the second era. Thus, roads were made up of two or three layers, depending on the traffic the road was to take. Conservation work took many forms, but generally consisted of cleaning and construction of ditches and road surface repairs.

The percentage with an asphalt cover grew rapidly over this era; indeed, in many areas nearly all the low volume roads laid during this period were provided an asphalt surface. This asphalt surface is generally rather than, about 3-6 cm. Sometimes this asphalt is pre-mixed, but it was quite usual to place a surface treatment. A film of binder is laid on the road and then a layer of small uniform chippings is laid immediately over it. This process may be performed only once, but it is more usual to perform it twice (Figure 4) or even three times.

The use of rigid paving, using cement slabs placed over a granular base, became a common alternative in some areas with high rainfall. The laying costs are greater, but the maintenance costs are lower. Great improvements were also made in the quality of drainage works, with drainage elements made of industrial materials such as steel, concrete, fibrocement and plastic (which are easy to install and repair) much more used.

The use of traffic signals became generalised and signs warning of loose animals or dangerous curves are now common in low volume roads - something unthinkable in earlier eras.

Administrative and economic framework of low volume roads

Ownership and functions of low-volume roads

The ownership of low volume road networks constructed in irrigated areas was provisionally handed over, along with the irrigation infrastructure, to the *Comunidades de Regantes* (irrigation communities). However, the conservation of the irrigation ditches and pipes gave rise to problems that had to be solved before the definitive handover. In some cases this was delayed for years - even today there are some areas where the handover of certain low volume roads has still not taken place. In contrast, the low volume roads built in areas of land parcel concentration were normally handed over to local town halls once the administrative processing of the new parcels was complete. Thus, over time, nearly all low volume roads in Spain have ended up under the authority of local town halls, whose economic resources are generally restricted in rural areas. The total length of the low volume road system is now some 421,118 km (Gallego *et al.*, 2008a), of which 85.85% (361,511 km) is owned by town halls.

The length of the low volume road system represents some 63.3% of the total length (664,852 km) of all Spain's roads. The different regional administrative bodies are the owners of 11.45% of the country's low volume roads. It is important to note the majority of the low volume roads under the authority of the latter bodies have an asphalt surface. Thus, nearly all of Spain's low volume roads (some 97.3%) are under the authority of public bodies. The remainder are managed by private entities, *e.g.*, *Confederaciones Hidrogáficas* (Watershed management authorities) charged with the management of the water resources in the basin where a reservoir is found. Some low volume roads also exist to provide access to ports, or to provide the army access to its training grounds.

Spain is now divided into seventeen political regions known as *Comunidades Autónomas*, which are political and administrative divisions of the State with the aim of guaranteeing limited autonomy for different regions. At the beginning of the 1980s, the central government began to transfer powers - including the management of low volume roads - to the governments of these regions. However, only the *Comunidad Autónoma* of Extremadura has passed a law specifically devoted to low volume roads (Spanish Regulation, 2002). This general absence of specific legislation has led to low volume roads being governed by the legislation developed for normal highways, which has to meet that set out by State law (Spanish Regulation, 1988).

Low volume road networks were mainly designed to provide access to farming operations, which is an eminently private enterprise restricted to the primary sector. The planning of the network followed a traditional top-down policy, which has been typically implemented in developing regions after Second World War (Njenga and Davis, 2003). The central planning defined areas of prior interest where low volume road network should be constructed in order to modernise agriculture there. Thus, the needs and desires of local population were not considered in many cases. This caused the perception in the final users that they had not any responsibility in the maintenance of the roads.

Figure 4. Low volume road paved with a double surface treatment.

Moreover, low volume roads have adopted sometimes in Spain social functions that were not originally foreseen and should theoretically be performed by highways, such as communication between villages, the provision of access for emergency services (fire-fighters, police, *etc*.) and that to recreational or leisure areas. This change in the function of low volume roads has also been reported in other countries (Hough *et al.*, 1996; Jaarsma, 1997; Lugo and Gucinski, 2000; Tortora *et al.*, 2015), and their main consequences are the increase in average daily traffic and traffic loads in those areas subjected to this phenomenon.

The contribution of the primary sector to the country's gross domestic product has decreased for the last decades in Spain. European Union approved a rural development strategy (European Commission, 2006) for improving the working lives of rural citizens and helping to prevent rural migration away from the countryside (IDA, 2007). This has led to the diversification of economic activities in the rural areas, and has also produced a growing need for improving local infrastructures, including low volume roads. This process has occurred in many areas that were not considered a priority for the development of the low volume road network. On the opposite hand, many agricultural areas have been abandoned due to the migration processes, and the low volume road networks placed there are subjected to lower traffic intensities.

Finance mechanisms for the maintenance of low volume roads in Spain

As it has been explained, low volume roads are basically found in rural environments and local town halls are their main owners. Rural villages usually have very small populations and their economic activity is also reduced; thus, the economic resources available for the management and maintenance of low volume roads are much reduced too. In addition, neither the local politicians nor the final users took part in the planning of low volume road networks. This has led to an absence of sense of responsibility for the maintenance of the roads. The conservation tasks taken on directly by town halls are usually isolated repairs performed with no planning or technical standards in mind. The effectiveness of these repairs is therefore very low, with roads quickly returning to their former condition. Sometimes, a number of town halls have come together to buy machinery that they share to undertake maintenance tasks.

The lack of funds at the town hall level means that most low volume road repair activities are now financed by funds from the *Diputaciones Provinciales* (public bodies charged with managing the economic-administrative interests of Spain's provinces) and the *Comunidades Autónomas* (Moya *et al.*, 2011). When such funds are provided, projects have to be drawn up showing the type of work to be undertaken and the technical criteria to be followed. The true origin of the financing for these projects is usually European Rural Development Funds (FEDER and FEOGA). However, none of these activities fall within an organised conservation plan.

There is a growing tendency to consider that the users of a road should be responsible for its maintenance (Schliessler and Bull, 1994; Semmens, 2006), especially given the costs incurred (external costs) by environmental pollution. Indeed, taxes are beginning to be levied on the users of some roads, particularly in cities (Langmyhr, 1997; Pahaut and Sikow, 2006), where the external costs are much greater. Private maintenance of low-volume roads has been successfully implemented in Sweden (Malmberg and Ivarsson, 2006) by the direct users of the roads. However, such financing is questionable with respect to Spanish low volume roads due to several reasons.

From an economic point of view, there are few areas where users could support the economic maintenance of the low-volume roads. From a legal point of view, the transfer of ownership of a low volume road to the users, based on the promise of its maintenance and upkeep, requires a complex administrative process and is also hounded by practical problems. Even though a contract might determine the conditions of such maintenance, town halls would still have to make inspections to guarantee the terms of the contract are being met. Moreover, if the new owner failed to uphold any contractual obligation, legal proceedings would become necessary in order for deficiencies to be rectified or for ownership to be returned, all at a notable cost. On the other hand, it could be created a specific tax for the maintenance of low volume roads if they remain owned by public bodies. In that case, it is not guaranteed that the money collected for the management of a low volume road network would actually be spent on that project.

Further from a social point of view, the assignment of tax bills would be even more complicated since it would have to depend on the use made by each person of these roads. However, the benefits of preserving low volume roads would impact society as a whole, although with more force for certain groups. The mechanism proposed by Jaarsma and Van Dijk (2002) for two local road-maintaining governments in the Netherlands could serve as a guide for levying a conservation tax based on the usage of the network. According to their model, the basic facilities for reaching buildings and land parcels along a road should be paid by the rural estate owners, while extra facilities that enable inter-local traffic should be paid by all inhabitants of the community.

Thus, shared financing would be an adequate means of attaining a certain degree of sensitisation towards the conservation of low volume roads. This alternative has been adopted by some town halls, where road users should partly finance the repair of the low-volume roads. It would also allow people to better identify with the accessibility needs of people living in rural communities. In addition, good knowledge of local peculiarities would be needed to avoid the inclusion of - and taxation for - low volume roads not considered a priority by users.

Clearly, there is a need for the different public authorities to participate in and draw up plans for the management and conservation of low volume roads; the responsibility of each party should be clearly specified in the interests of the efficiency of this process (Robinson, 2004). As outlined above, it would seem that local town halls are in a poor position to guarantee the maintenance of low volume roads. Thus, it falls to the *Diputaciones Provinciales* - the next highest tier of government after local town halls - to manage them. These bodies have the structure and experience needed to tackle this problem. In any event, town halls should intervene in the planning of low volume road management and conservation since they are the main owners, know their needs best, and represent the population of principle beneficiaries of their conservation. Finally, it would be a good idea to try to involve the users of these roads, better sensitising them to the need for their conservation.

Repair costs of low volume roads in Spain

In all three eras, the authorities that built low volume roads transferred their ownership to local town halls under the sole condition that they become responsible for their upkeep. However, the lack of money suffered by rural town halls has led to the required periodic repair of these roads being rarely undertaken (Moya *et al.*, 2011). Within 10 or 12 years of their construction, many low volume roads were beyond repair, wasting the massive investment made by the State.

Gallego *et al.* (2008b) examined 41 low volume roads in different parts of Spain made during the aforementioned eras and using the exposed pavement types. A method developed by the present authors (Gallego *et al.*, 2008a) was used to determine their condition. The main conclusion drawn was that just 26.8% were in good condition; the majority were found to be suffering from a range of important deficiencies - most of which had to do with water evacuation, a general lack of traffic signs, and the deterioration of certain types of road surface. The results obtained by Gallego *et al.* (2008b) show that those low-volume roads in a best condition are placed in areas with high production or irrigated fields and those roads that provide communication between villages. The traffic that low volume roads have had to take has been much greater than was anticipated, and the types of vehicles that use them are also different to that once contemplated. Thus, low volume roads have taken on more functions than originally intended for them. Currently they not only provide access to agro-industrial exploitations, they also allow communication between villages and provide access to recreation areas - theoretically the functions of local highways. A budget was then drawn up for the repair of each road examined by Gallego *et al.* (2008b) (Table 1). The aim was to determine whether the present condition of these roads was related to the era during which they were built, the pavement type employed, and/or whether the adjoining land was under irrigation.

Table 1 lists the information used in the statistical analysis. With respect to the construction types, seven classes were recognised (Table 2): the normal construction types plus that of T7 (Table 2), which refers to roads made with granular material produced by crushing rocks found in the immediate vicinity.

A comparison was also made of the repair costs associated with low volume roads in irrigated and rain-fed lands (Table 3); the cost was found to be slightly higher for the rain-fed lands (14,950 € km^{-1} compared to 12,527 € km^{-1}), although this difference was not significant. It should be noted that in this analysis no atypical values were found, thus no low volume roads were excluded from the analysis. Therefore, a total of 41 low volume roads were considered for the analysis regarding the influence of the type of land adjacent to the road.

Table 1. Low volume roads in the examined sample: information used in the statistical analysis.

Autonomous region	Code	Decade	Type	Surface	Irrigation land	Length (km)	Repair cost (€ km^{-1})
Andalusia	RR1	1960	T2	P	NI	3.25	19,768.9
	RR2	1960	T5	UP	NI	2.53	21,343.2
	RR3	1960	T2	P	I	0.73	27,176.2
	RR4	1960	T6	UP	NI	0.43	4437.7
	RR5	1970	T3	UP	I	4.3	165.1
	RR6	1970	T3	UP	I	4.4	0.00
Aragon	RR7	1970	T4	UP	I	11.82	7966.8
	RR8	1940	T6	UP	NI	11.7	12,044.0
Murcia	RR9	1970	T1	P	I	3.4	3557.8
	RR10	1970	T1	P	I	3.9	3544.7
Valencian Community	RR11	1990	T1	P	NI	5.5	2834.9
	RR12	1990	T1	P	NI	1.7	2655.5
	RR13	1990	T2	P	NI	4.94	26,797.3
Castilla-La Mancha	RR14	1960	T4	UP	I	0.5	21,639.0
	RR15	1960	T4	UP	I	2.7	19,036.0
	RR16	1980	T2	P	I	0.7	6952.7
	RR17	1980	T5	UP	I	1.95	14,953.6
	RR18	1990	T5	UP	I	2.32	17,948.8
	RR19	1990	T5	UP	NI	0.49	32,735.3
	RR20	1990	T5	UP	NI	1.65	974.6
	RR21	1990	T2	P	I	2.3	2146.1
Castilla y Leon	RR22	1950	T5	UP	I	1.69	19,337.6
	RR23	1990	T5	UP	I	2.93	22,680.7
	RR24	1990	T3	UP	I	1.85	6404.75
	RR25	1980	T5	UP	I	1.75	22,608.5
	RR26	1980	T5	UP	I	0.68	18,945.0
	RR27	1970	T4	UP	I	2.5	11,234.9
	RR28	1970	T4	UP	NI	0.62	17,725.90
	RR29	1980	T7	UP	I	0.94	3552.8
	RR30	1970	T5	UP	NI	1.75	16,254.4
	RR31	1970	T7	UP	NI	0.95	6.0
	RR32	1980	T6	UP	NI	1.9	27,944.2
	RR33	1980	T6	UP	I	0.63	23,282.1
Extremadura	RR34	1990	T5	UP	I	8.61	9934.7
Galicia	RR35	1990	T2	P	NI	1.05	4484.8
	RR36	1990	T3	UP	NI	1.01	25,646.6
	RR37	1990	T3	UP	NI	1.25	720.0
	RR38	1990	T5	UP	NI	0.86	14,792.9
	RR39	1990	T5	UP	NI	1.14	22,308.0
Madrid	RR40	1980	T2	UP	NI	5.12	29,453.1
	RR41	1990	T1	P	NI	3.05	9315.2

P, paved road; NI, non-irrigable; UP, unpaved road; I, irrigable.

Influence of the construction era on repair costs

Table 4 shows the means, modes and standard deviations of the unit cost for repairing the different roads built in the different eras. The information for RR8 and RR22 was excluded since they were the only data available for the decades 1940 and 1950, respectively. In addition, RR4 was found to be an atypical value, and so it was also excluded from this analysis owing to the small cost of its repair when compared with those of the decade 1960. Those laid in the 1970s have a mean repair cost of 7469.96 € km^{-1}, significantly lower than that recorded for the other decades outlined. The low volume roads laid in the 1960s and 1980s have a similar repair cost (18,000-19,000 € km^{-1}), while those laid during the 1990s are somewhat cheaper to repair (12,648.8 € km^{-1}). A comparison of the medians also shows the low volume roads built in the 1970s to have the lowest repair costs, although in this analysis they are closer to those of the 1990s roads.

An analysis of variance (ANOVA) was then performed to detect whether there was any significant relationship between the variables analysed. Significant differences were detected between the repair costs for the roads of each era. Multiple range analysis using Fisher's least significant difference technique showed the cost of repairing the low volume roads of the 1970s to be significantly lower than those of the 1960s and 1980s. No significant differences were seen between the cost of repairing the low volume roads of the 1990s and those of any other decade except for the 1970s.

The low volume roads laid during the 1970s correspond to the second era of construction. This was a period in which low volume roads were entirely made by the State, when earth-moving equipment was available, and when experience in road construction had been gained. The low volume roads of this time were found to be even better conserved than those of the 1980s and 1990s which are mostly of the third era, during which the planning of low volume roads and the responsibility for their maintenance fell to the *Comunidades Autónomas*.

Influence of the construction type on repair costs

In the statistical analysis taking into account the construction type (Figure 5), low volume road RR41 was excluded due to its high cost of repair per unit length compared to the other roads in category T1 (*i.e.*, with an asphalt top). For the same reason RR36 was excluded; its repair costs were atypical for the T3 category (granular surface).

Statistical analysis of the repair costs for the remaining roads provided the results shown in Table 5. For this study, RR36 and RR41 were found to be atypical values, and therefore they were excluded since their repair costs were too high if compared with those obtained for the remaining low volume roads included within their same category (T3 and T1, respectively). Some construction types, such as T1, T3 and T7 (range 3000-5000 € km^{-1}) were found to have much lower repair costs than the others, which all reached mean values of over 15,000 € km^{-1}. From this study it could be checked that repairing costs for T1 were almost five times higher than those for T2. The use of artificial stabilised granular materials increase the construction costs with respect to those obtained when using natural stabilised granular materials. On

Table 2. Low volume roads laid in different decades according to construction type.

Pavement type	1940	1950	1960	1970	1980	1990	Total
T1. Standard stabilised granular materials with asphalt top	0	0	0	2	0	3	5
T2. Natural stabilised granular materials with asphalt top	0	0	2	0	2	3	7
T3. Stabilised with granular material	0	0	0	2	0	3	5
T4. Chemically stabilised	0	0	2	3	0	0	5
T5. Natural stabilised granular materials	0	1	1	1	3	7	13
T6. Dirt roads	1	0	1	0	2	0	4
T7. Rock chippings (macadam, jabre)	0	0	0	1	1	0	2
Total	1	1	6	9	8	16	41

Table 3. Costs of repairing low volume roads (€ km^{-1}) according to the type of land over which they run.

Type of land	Number of low volume roads	Mean cost	Median cost	Standard deviation
Irrigated	21	12,527.0	11,234.9	8775.45
Rain-fed	20	14,950.8	15,523.6	10,514.80

Table 4. Cost of low volume road repairs (€ km^{-1}) depending on the decade in which they were laid.

Decade	Number of low volume roads	Mean	Median	Standard deviation
1960	5	21,792.70	21,343.20	3197.79
1970	9	7469.96	6780.10	6491.55
1980	8	18,461.50	20,776.80	9399.34
1990	16	12,648.80	9624.96	10,672.10

the other hand, the use of better materials (artificial stabilised granular materials) enhances the quality of the pavement and prevents its deterioration, thus significantly decreasing the repair costs needed after construction. In addition, it seems that the presence of the asphalt top did not have a significant influence on natural stabilised foundation (T2 and T5). However, it seems that greatly affects to the artificial stabilised pavements (T1 and T4). Comparison of the median costs showed the same trend. ANOVA (the Cochran test showed equivalence of variance) was performed to determine whether the unit repair costs depended on the construction type. In this analysis, the null hypothesis can be rejected (confidence 99%).

Multiple range analysis showed that two groups of very different costs exist (Table 6); group A, which included types T1, T3 and T7 (mean repair cost 3021.5 € km^{-1}) and group B which included T2, T4, T5 and T6 (mean repair cost 17,134.7 € km^{-1} - over five times that of group A). For the same reason commented for the analysis conducted at Table 5, in this analysis RR36 and RR41 were excluded.

The common denominator of the group A types is the use of good quality construction material (artificial stabilised granular materials, asphalt products, stones) and the use of well defined technical standards (stabilisation with granular material and artificial stabilised granular materials). The construction types in group B generally made use of poorer quality materials - directly in the case of natural stabilised granular materials, indirectly in the case of chemical stabilisations, which imply the use of low quality granular material. Neither were some of the group B roads subject to any exhaustive control of their actual laying, *e.g.*, dirt roads (T6). Thus, the present results show that while the use of better quality materials involves a higher cost in the construction of low volume roads, significant savings are made in their long-term maintenance and repair.

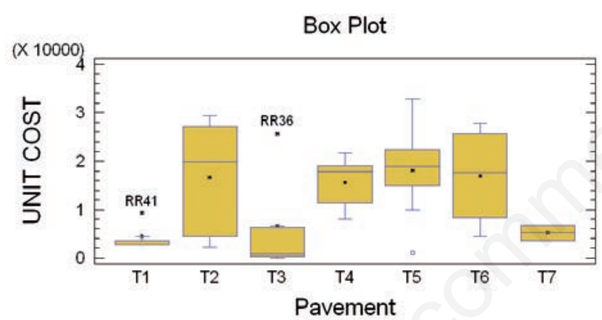

Figure 5. Box plots representing the costs of repairing low volume roads (€ km^{-1}) according to their construction type.

Conclusions

The development of a large-scale network of low volume roads requires that human and material resources be efficiently managed. Good planning is therefore vital. Low volume roads form an infrastructure whose design and construction need to be adapted to the environment where they are to be laid. Abundant information on the topography of the area is therefore needed, as is information on the soil type and the local availability of any materials that can be used in their construction. The following conclusions can be drawn from Spain's experience in developing the country's low volume road networks:

- The construction of a general network of low volume roads requires adequate technical and human resources are available. The use of new construction techniques can be problematic if the personnel in charge do not have the required training. Therefore, on occasion it might be expedient to use an older technology better known to the personnel available.
- The development of a countrywide network requires centralised planning that follows well-established steps and criteria. The rapid expansion of rural networks around Spain was possible thanks to the use of centralised plans and guidelines; these allowed common criteria to be applied in the investment of funds. This represented an optimum use of resources in the design phase and in the technical direction of the project, and allowed a rapid assessment to be made of the viability of alternatives presented in different areas.
- The condition of low volume roads depends largely on the implication of users and local politicians during their planning and the final use they are given by their users. It is therefore essential that users be sensitised to their correct use. This might be achieved through the production of guidelines and the direct involvement of users in conservation plans.
- The low volume roads laid during the so-called second era of construction are currently those in the best state of repair. These roads

Table 5. Repair costs (€ km^{-1}) for low volume roads of different construction.

Surface type	Number of low volume roads	Average	Median	Standard deviation
T1. Artificial stabilised granular materials with asphalt top	4	3148.2	3189.8	471.1
T2. Natural stabilised granular materials with asphalt top	7	16,682.8	19,769.0	11,830.8
T3. Stabilised with granular material	4	1822.5	442.6	3070.3
T4. Chemically stabilised	5	15,520.5	17,725.9	5702.7
T5. Natural stabilised granular materials	13	18,062.9	18,945.0	7473.1
T6. Dirt roads	4	16,927.0	17,663.0	10,670.7
T7. Chippings from rocks (macadam, jabre)	2	5166.4	5166.4	2282.0

Table 6. Costs of repairing roads in groups A and B (€ km^{-1}) according to construction type.

Group	Number of low volume roads	Mean	Median	Standard deviation	Standard error
A (T1, T3, T7)	10	3021.55	3189.77	2337.38	739.15
B (T2, T4, T5, T6)	29	17,134.70	18,945.00	8467.33	1572.34

were made by the State, making use of earth-moving equipment and the experience gained in over fifteen years of previous construction projects. The low volume roads of this era are even better maintained than those laid in the third era, when responsibility for their construction became that of the *Comunidades Autónomas*. The roads of this era were not made to the same quality as those of the second era.

- Low volume roads made with better materials and using standardised techniques last longer. The use of higher quality materials may involve an initially greater outlay, but in the mid and long term the repair costs are lower. The repair costs of low volume roads constructed with higher quality materials were found to be five times lower than those associated with roads made of lower quality materials.
- The transfer of ownership of low volume roads from the State to town halls has led to their almost complete abandonment and their generally showing a very poor state of repair. The scant economic resources of town halls have meant little money has been available for repairing low volume roads. It would therefore seem that the different public authorities of Spain should contribute towards financing the conservation of these roads. It might be better if they were owned by more solvent authorities; this would help to guarantee their upkeep. In Spain, either the *Diputaciones Provinciales* or the *Comunidades Autónomas* might be the ideal owners, especially the former since they represent the next tier of government after local town halls.

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