LA QUALITE DE SERVICE DES ROUTES

EVALUATION, PERCEPTION ET COMPORTEMENTS INDUITS DES USAGERS

THE QUALITY OF ROAD SERVICE

EVALUATION, PERCEPTION AND RESPONSE BEHAVIOUR OF ROAD USERS

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I. INTRODUCTION

I.1. General definition of the quality of service

Quality of service can be defined as the capability of a product or a service to meet the potential or expressed needs of customers or, more broadly, of the beneficiaries of the product or the service. This definition can be further qualified as follows:

- The customer is the main beneficiary of the quality of service but is not the only beneficiary,
- For various reasons, he may change his perception of quality,
- This definition of quality contrasts with the old concept of a high-performance product. The aim is now to comply with real needs. Quality is consequently not defined in the abstract but always for, and if possible with a road user,

- A service that is too costly cannot satisfy the user. Cost cannot therefore be dissociated from quality.

I.2. The specific context of the road object

The road is not an ordinary product. The creation of a road object forms part of a complex overall process in which the political dimensions of land use planning, socio-economics and environmental protection often take precedence, in the early design stages, over the purely technical problem of defining the intrinsic characteristics of the object. Moreover, although the term "customer" is not entirely appropriate for the road object, neither is it satisfactory to limit the beneficiaries of road quality solely to the users. The beneficiaries taken into account in an evaluation of the quality of service are generally:

- the users themselves,
- external beneficiaries, who include not only residents but also, from the perspective of planning and balanced land use, all taxpayers and elected representatives,

- the road owners, for whom the road is built and who are in charge of defining the planning aspect and technical specifications, who must finance it, possibly with the participation of co-financiers,

- the managers, in charge of operating and maintaining the road, including the police.

Another distinctive feature of a road is the time taken to plan and design it. Between the idea of a road project and its completion, ten or even twenty years may pass. And the lifetime of a road is also several tens of years. With such time scales, the anticipations of road owners and designers will have a considerable impact on the final quality of the road object. Road designers must predict future needs and constraints, which means involving future road operators in this aspect of the project as early as possible in order to address their requirements better. Such a long-drawn-out planning and design process considerably increases the risk of a discrepancy between the real needs initially recorded and the final offer of service.

I.3. Objective

The main aim of this paper will be to answer the following question:

Taking into account their budget constraints, what levers can road infrastructure owners, designers and operators use to optimize the quality of service and to make supply more consistent with demand for quality of service?

The question thus formulated admits implicitly that measuring the quality of service is not an end in itself. It only has meaning in relation to the aim of adjusting supply to service demand or vice versa. This paper will show that this aim involves preventive measures just as much as a curative measures.

To achieve its objective, the paper will address three basic series of questions:

1. It will first give some guidelines on how to better define and measure the quality of service, by answering the following questions:

   - What are the quality-of-service criteria or indicators?
   - What are the factors (or parameters relevant to the road's structural and maintenance aspects, traffic conditions and operating systems) that enable quality-of-service criteria to be quantified and/or evaluated?

   These questions will be considered in parts II, III, IV and V.

2. The paper will then give some elements of appraisal of how the user perceives the quality of service. It will analyze the conclusions to be drawn in terms of their behaviour. The following questions will be examined:

   - How do users perceive the quality of service of a road?
   - Do they have any perception of the technical quality of service, especially the intrinsic performance of the road and its ancillary services such as maintenance and operations? What are the main indicators of this perception?
   - Against what operational criteria do users judge the overall quality of service?
   - What effect does the perception of quality of service have on their behaviour?
   - How and using what indicators can the behaviour of users be characterized? How can it be measured?
   - Which aspects of the quality of service perceived by users influence their behaviour and in what ways?

   These questions will be addressed in parts VI and VII.

3. The paper will then outline some elements of a reply to a final question:

- How can quality-of-service criteria be combined to achieve an overall expression of a meaningful service level in physical terms i.e. how can users be convinced that many diverse factors can affect the quality of service, in a way that will enable them to understand and react?

This question will be addressed in part VIII.

I.4. Target and scope, basic data

The basic scope of this paper should sanction it as a tool for road owners, designers and operators.

Although the quality principles and criteria described in this paper are general in scope, the values assigned to them, and their priority ranking, may vary considerably with levels of development or motorization in different countries. No doubt, it is because of the composition of the group that has drawn up this paper, that most of the examples are taken from developed countries whose motorization goes back quite some time. The specific approach to the quality of road service in developing countries would need to be examined within the scope of another report.

The quality-of-service concept will be examined for all road types. Special emphasis will be placed on "intermediate roads", midway between motorways with two separate carriageways and ordinary single-carriageway roads. The paper will focus on the quality of service consistent with available methods and resources, giving particular importance to the amount of leeway available to owners, designers and operators to better tailor supply to service demand, taking into account the available resources.

The source data for this paper were collected from the meetings of PIARC Committee on Roads, Transport and Regional Development (C4), in connection with the work of Group C4.3 on the subject of: "Affordable quality of service". A questionnaire was drawn up and the replies and annexed documents form the basis of input for this paper. A bibliographical list of source documents is given in at the end of the paper.

II. QUALITY-OF-SERVICE IMPLICATIONS THROUGHOUT THE LIFE CYCLE OF A ROAD PROJECT

II.1. Technical quality of service and overall quality of service

Technical quality of service and overall quality of service are two core concepts which are clearly differentiated.

- The technical aspect corresponds to the supply, i.e. the technical means implemented by the road owner and the manager to address the intrinsic features of the road and ancillary services such as maintenance of the road, its equipment and traffic operating measures.

- The overall aspect is more concerned with road operating as it results from. matching the technical supply against demand and against the perception and response behaviour of users and residents. It involves in-use performance evaluated using indicators based mainly on the user's perception and behaviour: for example, speeds in free-flowing traffic, accident rates or user satisfaction rates. This performance integrates the traffic level and, in general, the actual demand for all the components of the service.

II.2. Basic quality-of-service objectives

The basic quality-of-service objectives usually set by project owners and implemented by designers and operators, vary according to the local context. But they are predominantly those in the reference list given in table 1, with greater or lesser individual weight according to the specific case.

Table 1: Basic quality-of-service objectives

Road-related Functions	Basic Quality-of-Service Objectives
Road functions	• Safety • Travelling comfort (reduce inconvenience and increase trip reliability) • Services to users
Environmental functions	• Integration of the road into the human environment • Integration of the road into the natural environment
Planning functions	• Access to urbanized areas and work areas, opening up of regions • Support and promotion of regional activities
General economic functions	• Enhancement of the overall benefits to users and public authorities • Reduction of the overall economic cost • Reduction of the road maintenance and operating cost

Achieving these quality-of-service objectives is a concern that begins in the earliest stages of the road designing process. It continues during the operational phase, i.e. throughout the life cycle of the road project.

II.3. Quality criteria relevant to the design process

The quality of service must be defined before building the road. This task encompasses the process of defining the specifications, the project and ultimately the construction of a new road (or a network of new roads). The quality of a road is the result of a number of stages:

- formulating the needs of customers, users, residents, local authorities, central government,
- defining quality-in-use, which involves translating these needs into the technical specifications, requirements or performance ordered by the project owner from the project engineer,
- developing of a project by the engineer, which expresses this order in technical and economic terms,
- awarding the works contract,
- building the works,
- monitoring compliance and acceptance of works.

Quality is the result of the activities of everyone involved in the various stages from design to completion of the project. Table 2 (p 19) gives a list of quality criteria to be met in the project owner's order and in the designer's response, in terms of both processes and results, to ensure the final quality of the road object.

Time is one of the important dimensions of project quality. It cannot be emphasized too strongly that it takes a long time to study a project well, whether for evolving specifications or developing solutions. Whereas end quality cannot be dissociated from technical quality, which is the responsibility of the project engineer, functional quality is the entire responsibility of the project owner. Right from the start of the project, the owner's concern must be to take into account not only the priorities of the beneficiaries but also the opinions of the various stakeholders, with whom he must establish efficient dialogue and communication. He must also implement proper programming which will allow enough time to study the project.

In the specification phases, it is the demonstration and prior communication of project quality that will determine the completed works. During these stages, it is not enough merely to state intentions. Using a number of perceptible criteria, the beneficiaries and the various partners must be persuaded of the benefits and the quality of the project. They must be satisfied that it will meet their potential or expressed needs. This is the point at which the main oppositions are voiced, mostly by residents and for environmental reasons. It shows that a perception of the future road already exists prior to its physical existence.

This perception will trigger reactions to, and adjustments of, the project – such as those aimed at reducing environmental impact. These adjustments will not be without effect on the final quality and cost of the project. It is also during the early stages in the design process that the quality-related options will incur the greatest commitments in the overall cost of the works. It is usually accepted that 70% of the cost of a project is committed at the time of drawing up the project specifications (or programme), even before starting the design studies.

Table 2: Quality criteria during the project development stages

Stages in the Process	**Project Quality Criteria**
ORDER BY PROJECT OWNER (Formulation of requirements)	Quality of order - good definition of requirements to be met - involvement of external practitioners - control over constraints and data - appropriate performance/costs/lead times
RESPONSE FROM PROJECT ENGINEER (Project design and construction)	Compliance with order *Quality criteria relating to the design process* - technical, administrative and financial control - compliance with lead times - compliance with target costs and estimations - project economics *Quality criteria relating to the object (result)* - reliability and justification of the solution - serviceability (see road functions in table 1, p 15) - ease of maintenance and operations - environmental integration

II.4. The implications of measuring quality when the road object is in operation

Once the road has been built, it must be monitored and the quality of service assessed. The task will then encompass the management and maintenance of an existing road (or network of existing roads) with the aim of anticipating, influencing or even modifying the quality-of-service pattern.

Upon opening to traffic, the road object must be consistent with the owner's order, failing which road quality cannot exist because a project is expected to translate the owner's order into technical characteristics. This order is theoretically the reflection of the beneficiaries' potential or expressed needs.

On roads recently opened to traffic, the main challenges consist in showing that the built object complies properly with the project and that any commitments by the owner to reduce environmental impacts have been met.

On older roads, the challenges consist in introducing methods of control, diagnosis and evaluation of the intrinsic features and in-use performance of the network, based on the processing of quantitative and qualitative data. The aim is to define programmes for maintenance and operation, and even for rehabilitation or renovation of the characteristics of a road or road facilities. The scope can be as varied as maintenance of pavements, roadside facilities or engineering structures, safety operations, emergency response, and traffic management. Measuring the quality of service by evaluating a network of existing roads is justified by the considerable interests at stake in terms of traffic management, safety, asset preservation and service to the user. The results of this evaluation will determine the budgets to be devoted to road management.

II.5. In summary

In essence, the groundwork for the quality of a road is laid in the earliest possible stages of its life cycle, which is before construction, during the formulation of specifications and throughout the design stages of the project. It is during these stages that owners, designers, and future operators, where known, have the greatest scope to invest in the quality of the future road object. But these are also the stages in which mistakes are most likely to be made owing to uncertainty as to the way the expectations of users and residents will change. When the road is in operation, the maintenance and operation practitioners go into action. The quality of service must naturally be controlled, and therefore measured, in order to design preventive or curative maintenance programmes, operating programmes and the proposed safety or traffic operations. The first quality criterion is compliance with the owner's order and with the project. Then other criteria must be added, some of which will have already been used in the design stage. These criteria take into account the "ageing" of the road object and the changing patterns of its use and its surroundings.

III. THE TECHNICAL QUALITY OF SERVICE OFFERED BY OWNERS AND OPERATORS

III.1. Towards more flexible use of standards

Let us turn our attention for a moment to the definition of the quality of service given in the introduction, and to some of the bibliographical information collected by member countries in preparing this report.

Quality is the response to the customer's expectation. This means that any supply below or in excess of this expectation cannot be considered as high-quality in the strict sense of the term. This is particularly true where the cost of this supply exceeds that of a supply that would have been more consistent with the actual demand.

Two highly instructive documents can focus thinking on the technical quality of service onto a few core ideas that clarify the definition of quality. These two works of reference, initially concerned with different problems, converge towards the same idea that a design standard is a prerequisite for attaining a satisfactory level of quality meeting such fundamental expectations as road capacity, speed and safety. This standard must offer adequate flexibility to the road owner, designer and operator. It must enable them to adapt their technical supply to complex realities, whether these are conflicting quality objectives or, more simply, safety and environmental constraints or economic considerations.

From the United States, the handbook "Flexibility in Highway Design" contains in itself the whole philosophy of quality, which is that of adjusting supply to demand. It demonstrates that road designers may refer to standards but these standards are not inflexible. They often have adequate working margins to adapt their technical solutions to local contexts and to address specific safety constraints and the environmental impact of the project. Project quality is not just compliance with reference standards. It is achieved by the intelligent use of the latitude allowed by the standards and by fine-tuning. The problem is that the two goals of safety and reduced environmental impact often call for conflicting solutions. For instance, improving an alignment may have a positive effect on safety but a negative effect on the environment. The solution to this contradiction may not lie in upgrading characteristics on an ad hoc basis. It may be worthwhile to take a fresh look at the entire road with a view to lowering the overall design speed when rehabilitating the road, rather than increasing this speed on a specific section. In the United Kingdom, the concept of flexibility has been applied to formal derogations from standards.

Since 1981, derogations from standards on the alignment could be obtained by road designers, subject to approval from the Central Authority of the Department of Transport. Since 1993, further "leeway" has been added, which can be used in predetermined circumstances and does not require recourse to the central authority.

The booklet from the Netherlands "Driving through a Road Environment" explains that the road user's behavioural errors are often due to the discrepancy between "what he expects and what he gets". This is particularly true on rural roads with 80 kph speed limits but with structural characteristics that permit higher speeds. The result: more instances of speeding, which cause accidents and disrupt the free flow of traffic. As it is difficult for motorists to constantly be in error-free control of complex driving situations on such roads – which are increasingly busy – accidents are frequent. The way to limit such misuse is to build "self-explaining" roads. These are roads which provide unequivocal information on what the motorist can expect to encounter and give him immediate feedback on any mistaken interpretation of the signals he receives. What are the features of such roads? It has been shown that driving pleasure, which determines driving speed, particularly on motorways, is influenced by a subjective perception of the environment, governed by emotional and cognitive factors related to previous experience. By ascertaining which environmental variables influence perception, and how they do it, a road can be designed to optimize the driver's subjective judgement if he adopts a driving speed consistent with the speeds desired by road designers and managers. The immediate environmental response will obviously not be the negative sanction of an accident. It may be a feeling of stress or discomfort resulting from the discrepancy between the sum of the efforts a driver is ready and able to invest in a driving task, and what is demanded of him by the environment.

III.2. Indicators of the intrinsic quality of the road

The aim of the following paragraphs is not to examine design standards in detail. For this, the reader will be advised to refer to existing handbooks specific to different countries. It is rather to show how standard practice offers freedom of scope to road designers to better adjust their supply to service demand.

The anchor points of the search for intrinsic quality indicators will be the main characteristics of the road. Each of these characteristics is defined by its basic technical components, considered as the key factors in the final quality of the road object (see table 3, p 27). We will examine more closely those marked with an asterisk.

For each of these components, the following aspects will be assessed:

- the most directly relevant fundamental quality objectives (with reference to table 1, p 15),
- the basic solutions adopted by different countries and the corresponding quality indicators. Emphasis will be placed on those theoretically perceptible by users,
- the adjustment margins around basic solutions and the tolerance with respect to minimum standards. Margins and tolerance will be assessed with reference to the most directly relevant fundamental quality-of-service objectives, particularly those concerned with safety, environmental impact and economic constraints. They will be placed in the context of experience in the various countries.

Table 3: Basic technical components of the quality of service

Main road characteristics	**Fundamental technical components of the quality of service**
Planning option	1 Road type*
Road category	2 Design speed*
Cross-section	3 Number of lanes* 4 Lane widths* 5 Safety zone (no aggressive obstacle)* 6 Recovery zone* 7 Central reservation*
Horizontal alignment, vertical alignment	8 Minimum radii* 9 Stopping sight distance from obstacle* 10 Overtaking sight distance* 11 Roadside masking objects 12 Co-ordination between horizontal and vertical alignment 13 Steep gradient areas
Junctions	14 Interchange spacing* 15 Junction types*
Pavements	16 Pavement types 17 Surface characteristics
Ancillary areas	18 Area spacing* 19 Area facilities*
Environmental integration	20 Landscaping 21 Roads through towns and villages
Safety and comfort signs and facilities	22 Safety barriers 23 Signs and information 24 Road marking 25 Noise barriers 26 Guidance systems* 27 Lighting
Engineering structures	28 Structure type

III.2.1. The planning option

Associated quality objectives

All the quality objectives in Table 1 (p 15) are relevant to the choice of road type. Note that this choice is an initial result of preliminary studies on land use planning and ancillary services. In the subsequent road project study, it is the choice of alignments and the interchange system that will meet the planning objective most closely on a more localized scale.

Road network typology

Many countries have adopted an administrative and structural classification of their road network, or concomitant definitions of different road types. A road type usually corresponds to a specific field of use in terms of:

- land use planning: structural or non-structural routes, long and medium haul traffic or local traffic,
- level of comfort: acceptable traffic levels, permissible speeds, services to users,
- safety: division or no division between traffic streams, interchange types, ancillary facilities,
- the environment: rural area, urban area.

This classification gives an initial idea of the intrinsic quality of service provided for the road. It is usually formulated by project owners in the planning or operation master plans for their road networks. It is therefore in itself a ranking of the intrinsic performance levels of the road network, insofar as the best performance tends to be associated, both in people's minds and in reality, with the highest planning, operation and maintenance levels of the network. This practice is justified by the owner's and operator's concern for the road to be self-explaining to users. The former must clearly announce their planning and operation objectives and the latter must easily be able to recognize the type of road they are about to take and the advantages and disadvantages they will encounter.

Two basic road types are usually distinguished:

- dual carriageway motorways,
- single carriageway ordinary roads.

To these two road types, intermediate types must be added, which provide a better performance level than ordinary roads at a much lower cost than a motorway. It is in the intermediate roads that road designers will find maximum flexibility.

Thus the fact of belonging to a well-identified road type is in itself a quality criterion. But although this is meaningful for motorways and "ordinary roads", which are the most easily recognized in practice by users, the same is not true for intermediate roads which do not have such a clear-cut typology owing to the widely-varying performance levels related to their intrinsic characteristics.

Limitations of a structural classification

A structural classification based on technical solutions has the foregoing "legibility" advantages but it also has disadvantages:

- It tends to reduce the choice of road type merely to an alternative between a motorway and an ordinary road, and to overlook intermediate roads. This is probably due to an oversimplified vision of road functions in which the objectives and service levels are not made sufficiently explicit,

- It increases the number of solutions to be implemented. This may be due to a concern to offer optimum performance where users would be satisfied with less, or to a commitment to make the roads more homogeneous, which is not necessarily a bad thing. But it results in another disadvantage. As performance criteria are often reduced to the recognition of an improvement or lack of improvement irrespective of the actual need, users are becoming increasingly hard to please because they are used to being given the most luxurious road characteristics.

Functional classification

Another less often used network classification does not express performance implicitly through road types but as functions with their corresponding service levels. The North American Road network is an example of this classification. The 6.3 million kilometres of roads and streets in the United States are functionally classified into arterials, collectors and local roads and are further subdivided into rural roads and urban roads. The arterials, which include freeways, provide high mobility levels and access control whereas the local roads provide greater accessibility to local property but lower mobility levels. The collectors offer a compromise between the other two types. France is endeavouring to go still further by orienting its transport infrastructure master plans more towards service policies.

Obviously, the only way for a functional classification to have the advantage of more open solutions than a technical classification, is by not automatically reducing this functional classification to a technical classification through systematically tying a technical solution to it. The immediate advantages of the functional classification are greater flexibility in road owners' policies, enabling them to avoid confining their road improvement plans to long-term solutions and correspondingly, greater flexibility in adjusting to spatial or temporal variations in demand. For example, it gives designers greater latitude by leaving them free to choose geometrical characteristics from the range of standards adapted to the particular functional class.

III.2.2. Road category, design speed

Associated quality objectives

The quality objectives associated with design speed primarily concern driving comfort and safety if the problem of transitions between successive road categories is taken into account. The will to integrate the road into the environment or to minimize investment costs by a less rigid alignment and longitudinal section may motivate the choice of design speed.

Clarifications on the design speed concept

Users indirectly perceive the design speed because it gives rise to different levels of comfort. It will be useful to clarify this concept of the design speed because approaches may vary from one country to another.

In France, the design speed forms part of the concept of the road category. Several speed categories can correspond to one road type and the choice of speed will be based on topographical constraints and their financial implications, while remaining within the limits consistent with that road type. For example, on type R roads, which are multi-functional roads forming the greater part of the rural main road network, there are two categories: R 60 and R 80. The category-defining index corresponds to the basic speed in AGR agreements, and to the "design" speed. The category will determine the minimum characteristics of the horizontal and vertical alignment and the superelevation characteristics. To calculate stopping and overtaking sight distances, the values taken as references will be the speeds actually travelled by motorists (conventionally V 85: speed below which 85% of vehicles travel in free-flowing traffic) estimated at each point along the road, in relation to the main geometrical characteristics of the site (see Table 2, p 19: V 85 speed in relation to radius). Whatever the case, choices of category and V 85 speeds are not independent from each other. It is the knowledge of the user's expectations and behaviour (actual travelling speed) in a given environment that is the determining factor.

In the United States, the design speed is the maximum speed that can be maintained over a road section when the conditions are so favourable that only the geometrical characteristics influence the speed. The choice of design speed is usually related to the type or functional classification of the roads. It is readily accepted, for example, that a through highway permits a higher design speed than a local road. Topography and adjacent land use are also determining factors in the choice of design speed. Here again, objectives consistent with road functions and the dynamic comfort of users form the basis for road designers' choices.

The choice of road category must be open

The choice of category or design speed, which primarily affects driving comfort, must be sufficiently open to enable the designer to adapt the geometrical characteristics to variations in topography or traffic. However, he must be careful in addressing transition zones. A change in road category or design speed must only be made if there is a clearly perceptible change in topography and environment – such as entering a residential area or a mountainous area. Another good reason for acting on the design speed is that of reducing the investment cost by optimizing the horizontal and vertical alignment. Lastly, an appropriate choice of design speed, coupled with careful co-ordination of the alignment and the longitudinal section, can considerably reduce the road's impact on, or even integration into, the environment.

III.2.3. Cross-section / number of lanes

Associated quality objectives

Like in the choice of road type, all the quality objectives given in table 1 (p 15) are relevant to the determination of the number of lanes, which also depends closely on the road type. The number of lanes must be considered from two angles:

- the number of lanes necessary for free traffic flow,
- the distribution of the lanes in the cross-section, which is guided by quality objectives or additional constraints.

Capacity and quality of traffic flow

The absolute maximum hourly flow that a two-lane road can carry in a short time interval is evaluated at 2,700 to 2,800 pcu/h (passenger car units per hour) However, it is estimated that above 2,000 pcu/h, corresponding to the design capacity of a two-lane road, traffic conditions begin to deteriorate. The determination of the number of lanes of a road section is thus tied to objective traffic-level-dependent data on the one hand, and to subjective considerations related to the degree of acceptance of a certain level of deterioration in traffic flow conditions, on the other hand.

The most in-depth reference on the subject, is undoubtedly American, with the Highway Capacity Manual (HCM), last completely revised in 1994 (HCM94) and with some updated sections issued in 1998. Many countries have based their own methods of describing traffic conditions on the HCM, whether for determining lane capacities or evaluating the service level in terms of traffic flow quality (congestion levels). The quality of traffic flow can be characterized by a number of indicators (III.2.3 c). These indicators categorize traffic flow quality according to different service level classes, from A to F (A corresponds to the lowest congestion level and F to the highest level). Conversely, the *a priori* choice of a service level class for a road section makes it possible to check whether the theoretical capacity of this section is acceptable and to increase or reduce the number of lanes accordingly.

Factors of capacity and traffic flow adjustment

The capacity of a road section and the quality of traffic flow are affected by a number of factors related to the physical characteristics of the road and its surroundings, and to the conditions of traffic flow.

The physical characteristics that affect capacity and service level are first and foremost the infrastructure type. Other factors are relevant, which can initially be placed in the classes given in Table 4 (p 39). These factors of capacity and service level adjustment will obviously not all act with the same intensity on all road types. As it is their quantitative impact that is involved, it will be useful to refer to the HCM which gives the adjustment values corresponding to the relevant road types.

Traffic-related factors affecting capacity and service level are primarily the following: the distribution of vehicle types using the road section (presence of heavy vehicles), the distribution of vehicles per direction and per lane, the driver population (familiar or unfamiliar with the road section). Unlike the first factors, these adjustment factors are quite distinct from the designers' choices. Most of them can only be anticipated or are not precisely known during the definition stages of the technical quality of service and during the design stages themselves. However, they affect technical quality and designers and operators must take them into account to fine-tune their supply. In the United States it has also been observed that motorists are now capable of driving with inter-vehicle time intervals of less than 2 seconds, and at higher speeds and hourly flows. This motivated the revision of the HCM 85. The HCM 94 infers from this a 10 to 15% increase in capacity on expressways, which means that fewer roads than initially planned with the old calculation procedure will have to cope with congested conditions.

Table 4: Relative importance of capacity adjustment factors (reference USA)

Factors of capacity and road traffic flow adjustment on link sections	Separate carriageways and access control Uninterrupted traffic	2-lane roads and interrupted traffic	Intermediate roads
Junction types		+	+
Design speed	+	++	+
Speed restriction	+	+	++
Side and central visibility clearance	++	+	++
Number of lanes	++		++
Lane widths	++	++	++
Type of central separation	+		++
Verge widths	+	++	++
Verge structures and surfacing		++	++
Presence or absence of left-turning lanes		+	++
Possibility or impossibility of reversing central lane direction			+
Presence or absence of slow-moving vehicle lanes		++	+
Number of access points			++
Overtaking sight distances		++	+
Presence or absence of 2-lane dual carriageways or 3-lane overtaking gaps		++	++
Road section gradient	+	++	+
Presence or absence of traffic control signs		+	
Existence or absence of an "intelligent road" type of operating system	+	+	+
Type of land (topography, environment)	+	+	+

To introduce the next section, it will be helpful to give a few indications provided by France on the practical capacities of the different road types.

Table 5: Practical capacities of bi-directional roads (reference France)

Rural bi-directional roads		
Type (width)	Design capacity (in pcu/h) 2 directions	Conditions
5 m	1,300	flat ground
6 m	1,600	no major junction
7 m	2,000	60/40% traffic distribution
10.5 m (3 lanes)	2,700	

Table 6: Practical capacities of dual-carriageway roads (reference France)

Rural dual-carriageway roads	
Type	Design capacity (in pcu/h per direction)
2-lane dual motorways and high-quality 2-lane dual-carriageway roads	3,000
3-lane dual motorways and high-quality 3-lane dual-carriageway roads	4,500

To take into account the traffic data, the adjustment margins are those intrinsic in the adjustment factors given earlier and in traffic forecasts. In some cases, these forecasts enable the number of lanes required over the longer term to be built in stages. Another element on which it is possible to act is the provisional acceptance of some degree of deterioration in the service level. But there is relatively little room for manoeuvre if the road is likely to reach its saturation flow level within less than fifteen years. If such is the case, it is better to anticipate on the number of lanes.

Lane distribution in the cross-section

As regards the distribution of lanes in the cross-section, two main types of profile are available to road designers:

- dual-carriageway roads with 2x2, 2x3, 2x4 lanes,
- single-carriageway roads with 2, 3, 2+1, 4 lanes.

The road designer's actual choice of the number of lanes is situated at the margin of the practical capacities of the different road types. For example, between a dual-carriageway road able to benefit from ideal adjustment factors and a three-lane road, or between a 2+1 lane road and a 2x2 lane road. Over and above the capacity criterion supported by traffic forecasts, other elements are to be taken into account, of which safety is the most important. Then come savings in time and travelling comfort which, like safety, are criteria to which monetary values can be ascribed. Lastly, the decision to opt for a particular arrangement of lanes in the cross-section can be affected by concerns related to the environment, the topography or the overall coherence of the route.

Once the design capacity margins of the various profiles have been addressed, there basically remain two types of flexibility for 3-lane roads, 2+1 lane roads and 4-lane roads. For 3-lane roads, the conclusions presented in Montreal showed that 3-lane roads with a reversible lane are no more dangerous than 2-lane roads, provided that the lanes are not reduced to a width of 3 metres, the visibility distance is more than 500 metres long and certain precautions are taken in junction planning and verge treatment. The Montreal report also concluded that 2+1 lane roads have further safety-related advantages and that as regards free traffic flow, there is little difference between these roads and 2-lane roads. For 4-lane roads the adjustment margins are mainly safety-related and in fact conclude on the need for the traffic streams to be separated by a central reservation and for junctions to be treated, as shown by safety studies conducted on the Hungarian road network.

III.2.4. Cross-section / lane widths

Associated quality objectives

The choice of lane widths is primarily motivated by travelling comfort considerations, with a view to achieving optimum capacity. The impact of lane widths on safety is probably best demonstrated on urban links, where it must aim to facilitate the co-existence of pedestrians and cyclists, rather than on rural roads. Site integration objectives are therefore determining factors in the choice of lane widths. Lastly, reduced lane widths should result in decreased investment and maintenance costs, but this decrease is fairly marginal compared with the overall cost of a project.

Influence on capacity

Most countries adopt lane widths of between 3.5 and 3.75 metres. Theoretically a reduced lane width has an effect on capacity. On single-carriageway roads, table 7 shows the differences in design capacity between widths of 5, 6 and 7 metres. On divided-carriageway roads, a reduction in lane width from 3.5 to 3 metres does not seem to modify capacity to any significant degree. The following table, taken from HCM 94, suggests variations in capacity for highways, in relation to lane widths and side clearances. The 1997 updated version deals with these adjustment factors in two separate tables: one for shoulder widths in relation to number of lanes and one for lane widths.

Table 7: Single carriageways - Capacity reduction in relation to lane widths and side clearances (Reference USA)

Distance from road edge to obstacle (in m)	Adjustment factors for an obstacle on							
	one side of the carriageway				both sides of a unidirectional road			
	Lane widths							
	3.6 m	3.3 m	3 m	2.7 m	3.6 m	3.3 m	3 m	2.7 m
1.8	1	0.95	0.9	0.85	1	0.95	0.9	0.85
1.2	0.99	0.94	0.89	0.84	0.98	0.93	0.88	0.83
0.6	0.97	0.92	0.88	0.82	0.95	0.90	0.86	0.80
0	0.92	0.88	0.84	0.80	0.86	0.82	0.78	0.74

Influence on safety

On single carriageway rural two-lane roads, a reduction in lane widths is not a determining factor for safety, down to a threshold of 3 metres and even below. However, very wide two-lane roads are inadvisable safety wise. On three-lane roads, it has already been shown that a lane width of 3 metres is unsatisfactory. And on roads with divided carriageways, little is known about the effects on safety of a reduced traffic lane width down to thresholds of 3.25 m or even 3 m. Moreover, these effects must be analyzed by identifying the lane or lanes concerned in the cross-section and by taking into account the geometrical arrangements of the hard shoulders for emergency use or the shoulders or the left-hand leveled-down strips. On account of their many functions, reducing the widths of these strips seems to have greater effects on safety than reducing traffic lane widths.

Influence on comfort

The tolerance thresholds remain limited to a lower threshold which can be reasonably set at 3 metres for lanes of single-carriageway roads or divided-carriageway roads with little heavy lorry traffic. Reducing lane widths obviously has an impact on the comfort of users, particularly when they are heavy vehicle drivers, and the wall effects generated by these vehicles on light vehicles must be taken into account. Whatever the case, a reduction in lane width must aim to preserve the degree of homogeneity of the route and, above all, to avoid surprising the user. This means that it will also be helpful if width changes are made at points marking an environmental change, such as the entrance to built-up areas or the passage into a mountainous area. Note that if lanes are reduced in width, care must be taken when considering ancillary measures aimed at compensating for users' discomfort, which are liable to result in higher speeds and consequently greater risk of accidents.

III.2.5. Cross-section / safety zone without any aggressive obstacles

Associated quality objectives

These objectives are obviously safety objectives.

Width of the safety strip

In France, the safety zone, in which no obstacle is allowed, varies between 4 m for roads with 90 kph speed limits to 6.5 m for motorways with 130 kph speed limits.

In the United States the term "clear zone" is used to describe this safety strip. The width of the clear zone varies according to the traffic volume, speed and the embankment slopes. These relationships and procedures for determining the width of clear zones are contained in the American Association of Highway and Transportation Officials (AASHTO) Roadside Design Guide. For freeways, high-speed rural arterials and rural collectors with a design speed exceeding 60 kph, the AASHTO Policy on Geometric Design of Highways and Streets (Green Book) recommends following these procedures for determining the width of the clear zones. For low-speeds, less than 60 kph design speed, on rural collectors and local roads, the AASHTO Green Book suggest a minimum clear zone width of 3 m. For urban arterials, collectors and local streets where curbs are used or space is otherwise limited, a minimum 0.5 m offset to rigid objects is recommended.

Vehicles can leave the travelled way for many reasons; driver fatigue, inattention, excessive speed, driving under the influence of drugs or alcohol, or while avoiding a collision with another vehicle. The elimination of hazardous obstacles in the clear zone will have a substantial effect on a road's level of safety by reducing the severity of the accidents. If it is impossible to remove all obstacles from a safety zone, it is at least necessary to isolate the most dangerous obstacles by shielding them with guardrails or crash cushions, or by designing them so that they break away without causing sudden stops when struck by a vehicle. Such designs include breakaway sign and light supports.

III.2.6. Cross-section / recovery zone

Associated quality objectives

The recovery zone is the part of the verge closest to the carriageway, free of any obstacles and treated in such a way that it will readily accommodate users engaging in a "recovery" manoeuvre (correcting course or emergency braking). It is consequently an important factor of safety and comfort. North American studies have shown the relationship between the accident risk trend and the hard shoulder width on 2-lane roads. The risk is halved when the hard shoulder width is increased from 0.6 to 3 m. An extremely rigorous German study, covering 6,000 km of motorways, shows that motorways without emergency parking shoulders, have accident rates 24% higher than motorways with such shoulders. The influence of this zone on the road capacity is also a determining factor. The FHWA demonstrates that even where lanes have a normal width of 3.6 m, the lack of a verge or the presence of an obstruction at the roadside may result in a 30% capacity reduction compared with a section that has a verge or a side clearance width of at least 1.8 m. Another function of this zone is to permit the circulation of pedestrians, cyclists or farm vehicles. It facilitates occasional movements of maintenance and operation vehicles or of emergency call-out vehicles. The way this zone and the roadside in general are treated, will affect the investment and maintenance cost of the road. But its impact on safety make this treatment extremely cost-effective.

Quality criteria of the recovery zone

The parameters taken into account for the efficiency of this zone are the width, structure and treatment of the surface, including the slope. The width ranges given by the various countries vary quite considerably. They integrate the relevant road type, the level of traffic and the surroundings. In the United States, for example, the width may vary between 0.6 m for the most minor rural roads to 3.6 m for the most major roads. In the United Kingdom, the normal width recommended by the standard is 1 m on single-carriageway roads and 3.3 m on dual-carriageway roads. In France, the width varies from 2 to 2.50 m (3 m if lorry traffic is heavy) depending on the road type, and the recovery zone consists of a surfaced strip. The structure and surfacing of the recovery zone, including on the primary networks, may simply be a soft, grassy surface, but this is by no means the best solution to ensure the recovery function properly. In the more luxurious solutions, the recovery zone may consist of a real load-bearing structure and a wearing course. This is the case of heavily-trafficked roads whose service level objectives are ambitious, i.e. basically those of motorways. The maximum gradient allowed in France is 4% on rural main roads.

Adjustment margins for treatment of the recovery zone

The functions of the recovery zone are such that it is not easy to reduce the minimum mandatory widths. When running off the road at 90 kph, at an angle of 5°, in 1 second (response time) a motorist will find himself at 2.18 m from the outer edge of his lane. At 110 kph he will be at 2.70 m. Some tolerance or deviations may however be considered. According to British engineers, at the top of the range of widths used, a reduction to 3 m does not seem to impair the level of safety compared with greater widths. At the bottom of the range, the French consider that on main roads, widths of less than 2 m must be avoided as they may give the motorist the illusion that he can stop safely in an emergency. As for the structure and surfacing, the highest service level is clearly provided by a surfaced hard shoulder which, among other advantages, offers much greater skid-resistance than a grassy surface. On motorways, the justification of a high service level results virtually automatically in a strengthened, surfaced structure. The question of the structural or surface characteristics is highly relevant on "intermediate" roads, owing to financial constraints and to the fact that the service level objectives are usually lower than on motorways. On intermediate roads, the designer can adopt various technical solutions that enable him to reduce investment costs while preserving basic safety objectives. Stabilizing the shoulder is the least he can do. It is also possible only to surface the shoulder over part of its width. An important factor to be taken into account is that an over-generous verge must not lead the motorist to think that the road he is travelling has a higher service level than it actually has. The classical mistake, which is fatal in terms of safety, is to think that the road is a divided carriageway whereas it is in fact a bi-directional road. On local roads with low traffic levels and moderate speeds, it is difficult to provide anything less than a turfed shoulder, which we know will entail mowing costs but will have the benefit of being consistent with the environment and with the type of trip.

III.2.7. Cross-section / central reservation

Associated quality objectives

Safety objectives are essential when planning a central reservation. The reservation carries items of equipment, supports, service mains and plantations which also involve comfort objectives and maintenance and operation objectives.

Factors to be taken into account when planning a central reservation

The central reservation usually consists of an intermediate grassy or surfaced area on which safety barriers may be installed, on either side of which are two levelled-down strips varying in width between 0.75 and 1.50 m depending on the road type. The technical solutions adopted by different countries are equally divided between a central reservation more than 3 metres wide and a narrow central reservation. The adopted widths depend on the environment (rural area, peri-urban area) and the type of safety barrier on the central reservation. A reinforced concrete safety barrier reduces both the central reservation width and the risk of it being crossed by lorries. A very wide central reservation may enable some roads to do without safety barriers to achieve better landscape integration and to reserve space for subsequent widening of the carriageway. Naturally, the coincidence of vertical alignments of the two carriageways must be considered, together with drainage problems. Another factor not to be overlooked is the difficulty of access to the central reservation, which may result in maintenance and traffic operation constraints. Lastly, safety and comfort facilities, or landscaping of the central reservation have an effect on drivers' perception and behaviour (speeds, stopping sight distances, wall effect), which must be taken into account.

Adjustment margins for treatment of the central reservation

In the light of these factors, the adjustment margins for the road designer will primarily be concerned with treatment of the intermediate space and deciding whether or not to adopt safety barriers. The lower planning limit of the central reservation, already observed in some countries such as Hungary, is the absence of any treatment other than simple central marking, and the absence of a safety barrier. Hungary has made a general evaluation of 27 sections of 4-lane roads, among which the M0 with a continuous double central line and grade-separated junctions. This evaluation highlights the benefit of a turfed central reservation compared to simple road marking. In fact, Hungary suggests two types of central reservation for 4-lane roads. For the widening of 2x1 lanes into 4-lane roads: a separation by a 1.5 m wide surfacing on which a safety barrier is installed if traffic is heavier than 36,000 pcu; a turfed, 3 m wide central reservation if not. The latter solution is always adopted on new 4-lane road layouts.

The solution of a 3-m wide central reservation is far from being accepted by all countries. In France, for instance, the standard does not permit this solution and it is only with a central reservation more than 12 m wide, where the tourist traffic flow functions are important, that it is possible to consider doing without the safety barrier. This is the case proposed by the planning charter of National Road 10, for which road designers and operators agreed to fix the minimum width of the surfaced central reservations at 3 m with a double row of safety rails, and at 3.6 m with a concrete barrier, and planned not to install rails when the central reservation is more than 12 m wide. On motorways, the presence of a physical separator is mandatory.

III.2.8. Horizontal and vertical alignment: minimum radii

Associated quality objectives

The geometrical rules for horizontal and vertical alignment aim to ensure conditions of comfort apporpriate to each road category and to guarantee good safety conditions with regard to the sequence and combination of alignment elements and to visibility. It must be remembered that the optimization of the horizontal alignment and the vertical curvature can have a considerable impact on the environment and on the project economics.

Effects of the choice of radius values on the quality of service

The road users' discomfort is all the greater where the radii of the alignment curves are low. Low-radius curves can also create safety problems, particularly when they are isolated. However, although the systematic use of high-radius curves may be recommended instead of long, straight motorway alignments, they are not advisable on bi-directional roads. This is because they encourage high travelling speeds while limiting possibilities for overtaking in good conditions of visibility. Geometrical standards, from whatever country of origin, stipulate that successive radii must obey co-ordination rules to ensure safety. In general, below a certain radius value, the curves are introduced by gradual transitions formed of clothoid curves. The design rules for main roads laid down by France for its national network, recommend not introducing radii that are too low through excessively long clothoids, for reasons of safety and comfort. The United Kingdom's alignment standards make the same recommendations. French safety studies on bends have shown that a large disparity between the mean radius of an entire curve and the final radius is a factor of accidents. It also appears that an excessively long clothoid makes perception of the final curve difficult. French standards therefore propose limited clothoid lengths, depending on the road type and the radius to be introduced, in accordance with table 8 (p 55). In some difficult cases, it is possible to use shorter lengths than those in the table, or even to eliminate the gradual transition, particularly on roads in difficult sites.

Table 8: Clothoid lengths (Reference France)

2-lane roads	$L = 6 R^{0.4}$ (peak levelled down to 67 m)
3-lane roads	$L = 9 R^{0.4}$ (peak levelled down to 100 m)
2x2 lane roads (non-motorway)	$L = 12 R^{0.4}$ (peak levelled down to 133 m)

These gradual transitions may take other forms: ovoid, C-shaped and crested curves. But as these arrangements introduce curvature variations liable to surprise the motorist, they are not recommended.

The minimum values for the horizontal curves adopted by different countries are quite similar for the lowest design speeds but with greater differences for the higher speeds. Table 9 shows the variations observed in some countries, for design speeds of 120, 100 and 80 kph.

Table 9: Minimum values for horizontal curves

Design speed Kph	**120**	**100**	**80**
Germany	800	500	280
Belgium	770	492	260
Denmark	872	492	265
Spain	650	450	260
France	665	425	240
United Kingdom	720	510	360
Greece	800	500	200
Italy	667	350	260
Norway		430	230
Netherlands	750	450	250
Portugal	700	450	260
Switzerland	650	450	240
United States*	870	490	280

* These values are for a superelevation (banking) rate of 4%. Sharper curves are allowed for higher superelevation rates.

For the vertical alignment, the minimum values of radii with re-entrant (at the low-point of the valley) or salient (at the top of the hill) angles depend on the dynamic comfort (vertical acceleration) and, more particularly, on the stopping sight distance from an obstacle or the overtaking sight distance. It is always necessary to refer to real travelling speeds, which may cause higher salient angle radii values to be adopted than the minimum values recommended by the standard.

The minimum salient angle radii of the vertical curvature adopted by different countries are also quite different, particularly for the highest design speeds, where considerable variations may be observed. Table 10 (p 57) gives examples of the values used. To provide good safety, optical guidance and integration into the landscape, the alignment and the longitudinal section must be thoroughly studied to ensure their coordination. French rules state that for safety reasons, the beginning of the curves (particularly where their radius is less than 300 m) should not coincide with a high point of the vertical curvature. German rules state that in rolling country, the salient angle radius must be greater than the re-entrant angle radius, in order to facilitate the design of the road in terms of the visibility distances. But conversely, where there is a small difference in elevation (less than 10 m), particularly on plains, the re-entrant angle radius must be greater than the salient angle radius so that the alignment provides a satisfactory optical appearance. Where there is a superposition of a horizontal curve and a low point, the same rules stress the benefit of having the lowest possible ratio of the respective R/H radii. In fact, the German view is that an alignment has good quality visibility, surface water draining and kinematics when the inflection points of the horizontal alignment coincide with those of the vertical alignment.

Table 10: Minimum salient angle radii of the vertical curvature

Design speed	120	100	80
Germany	20,000	10,000	5,000
Belgium	12,000	4,500 (90 kph)	1,500 (60 kph)
Denmark	15,000	6,000	3,500
Spain	12,000	6,000	3,500
France	10,000	6,000	3,000
United Kingdom	18,500	10,500	
Greece	16,000	9,000	5,000
Italy	14,100	6,900	2,850
Norway		6,400	2,900
Netherlands	12,400	5,800	2,500
Portugal	14,000	9,000	5,000
Switzerland	20,000	12,500	6,000

Adjustment margins on the horizontal and vertical alignments

These geometrical rules which, moreover, only account for a small part of the standards laid down in the different countries, show that designers have considerable leeway for coordinating the horizontal and vertical alignments. It is true that they are advised not to descend below the minimum radii, mainly for safety reasons. But tables 9 and 10 clearly show the relative nature of such a recommendation, through the diversity of the thresholds. Some constraints can make good sequencing of successive radii, and coordination with the vertical alignment difficult and warrant deviations from standards. Such constraints are usually the result of a difficult site and may result in heavy additional costs where minimum standards are strictly complied with. Whatever the case, the tendency of designers is to go beyond the thresholds. This may have various justifications related to the quality of service but tends to have inflationary effects on project costs.

III.2.9. Stopping sight distances from an obstacle

Associated quality objectives

The main objective associated with stopping sight distances from an obstacle on the carriageway is obviously one of safety. Visibility requirements affect all aspects of design, and form a valuable indicator of the quality of a road project.

Influence of actual travelling speeds on visibility distances

To take into account actual travelling speeds, the conventional international method is to use the speed V 85, below which 85% of motorists drive. The sight distance from any obstacle on the carriageway must be greater than the stopping distance at any point along the trip path. It is common knowledge that this stopping distance consists in the braking distance plus by the distance travelled during the response time. On a curve, the braking distance is usually increased. France gives the following stopping distance values for V 85 speeds

Table 11: Stopping distances in relation to V 85 speed

V 85	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
d on a straight alignment	15	25	35	50	65	85	105	130	160
d on a curve	15,5	26,5	40	55	72	95	121	151	187

The international comparison of the minimum stopping distances values from an obstacle in relation to design speeds (see table 12) show some differences. This is because different friction coefficient values and response times are taken into account. It is also because some countries take into account speeds higher than the design speeds. This is notably the case of Germany.

Table 12: Stopping distances from obstacle

Design speed	**120**	**110**	**100**	**90**	**85**	**80**
Germany	330		230	230		180
Belgium	275		185			185
Denmark	255		180			120
Spain	221		171			125
France			160	130		105
United Kingdom	225		165		125	
Greece	280	230	190	155		125
Italy	229		160			103
Norway			175	147		119
Netherlands	260		160	135		105
Portugal	250		180			120
Switzerland	280		195			125
United States	203		180	131		113

Adjustment margins

Great care must be taken in their use because the safety factors are so important.

On the inside of curves, where the advisable side clearances to ensure the sight distance would result in extensive earthworks, it may exceptionally be permissible to allow a stopping distance for a straight alignment and/or to reduce clearances to a value that will maintain appropriate visibility for a sideways evasive manoeuvre to avoid the obstacle whatever the circumstances. Whenever visibility corresponding to the stopping distance is not provided, it is necessary to specify a clearly perceptible local reduction of the permissible speed (if necessary by using dynamic signing). It is also necessary for traffic operators to carry out close supervision of the road condition, particularly where there are risks of falling stones.

III.2.10. Overtaking sight distances

Associated quality objectives

Overtaking possibilities are an important criterion of the quality of service for users. They involve two essential quality objectives, which are safety and driving comfort.

Effects of overtaking sight distances on the quality of service

On multi-lane dual carriageway roads, overtaking possibilities theoretically exist all the time. In practice, when traffic becomes heavy, these possibilities are limited because the lanes are in use. However the concern with overtaking sight distances is mainly on bi-directional 2-lane roads and 3-lane roads where the central lane is not assigned. On these road types, it is reasonable to aim to ensure the overtaking sight distance over a sufficient proportion of the route length. France recommends at least 25% of the length, but without concentrating these 25% on a single section. The overtaking sight distances adopted by different countries for a design speed of 100 kph are between 400 and 700 metres;

Adjustment margins: providing overtaking gaps

The elements to be considered in the design are roadside masking objects, vertical salient angle radii, and mobile masking objects on curves to the right. Note that for an objective of 25% overtaking possibilities, there usually corresponds quite a considerable percentage of straight alignments. Moreover, straight alignments may also be subjected to overtaking restrictions owing to the vertical curvature or the presence of junctions. Under these conditions, the only solution for designers may be to provide 2-lane overtaking gaps, separated from the oncoming traffic by a continuous line marking, or preferably, by a traffic barrier. The question is then to know the optimum length and spacing of these 2-lane gaps. This is an inconvenience-related concern which will be examined more particularly in the section on measuring the overall quality of service. At this stage, a few interesting points can be mentioned, many of which were compiled for a recent French study on the search for a new road object.

As a general rule, 2-lane overtaking gaps of a few hundred metres are long enough to break up bunching traffic. After 800 m, the inconvenience rate is already nearly down to a minimum in most rural alignment and traffic configurations. The efficiency of the gap is usually a decreasing function of its length, where this length exceeds the threshold of a few hundred metres. The bibliography gives the following range of values (case of an isolated gap on a bi-directional road, based on a cost-benefit calculation): 800-1,200 m for 200 veh/h/direction, and 1,200-1,600 m for 400 veh/h/direction. For higher travelling speeds and lower speed differentials, the above values must be increased. The FHWA gives an increase of 45% of the minimum overtaking area lengths at 110 kph compared with those at 90 kph.

For the spacing of overtaking gaps, there is no real threshold. They depend on the service level criterion selected to characterize the traffic conditions. If speed is taken as the criterion, it is shown that after 2 km, there is already a distinct decrease. The regrouping process, or platooning,which begins as soon as the 2-lane gap ends, is gradual. It depends primarily on the dispersion of the desired speeds and naturally, on the traffic. Vehicles are inconvenienced all the more often, quickly and intensely when they are travelling fast. Relatively little time is lost on the road as long as the amounts of traffic and one-lane section lengths are not too great. For example, for 5 km lengths of one-lane sections, and for traffic of 250 veh/h, the trip time is increased by 11%, which represents 6 minutes for 100 km. For traffic of 500 veh/h, the time loss increases to nearly 10 minutes. However, it should be noted that the time loss (in %) is much less than the time spent in bunching traffic (in % of the total road length). Thus for this criterion, a moderate delay can nonetheless result in major inconvenience. Delays of 5%, 10% and 15% correspond to inconvenience lengths of 20%, 37% and 50% respectively. This shows that it cannot be taken for granted that the desirable distribution of the overtaking gaps, which corresponds to the economic optimum (trip time/cost), is the same as the distribution which provides traffic conditions considered acceptable by users, particularly for the fastest drivers.

III.2.11. Interchange spacing and junction types

Quality-of-service objectives

The main associated objectives are safety, comfort and economic objectives, the latter particularly on roads isolated from their surroundings.

Scales of improvement according to the road types

On roads with a high service level aimed at prioritizing long-distance traffic, improvements to junctions must be designed to limit inconvenience and deceleration. On these types of roads, which are usually divided carriageways but which may also be bi-directional expressways with limited access, it is logical not to allow frontage access and to provide systematic grade separation of interchanges. This option obviously requires considerable funding as transfer interchanges on motorways can cost between F20 and 40 million on average. Such high costs justify realistic cost-benefit studies, particularly on toll motorways where toll collection expenses are incurred. The problem is that public authorities and pressure groups in regions crossed by such roads often demand a large number of interchanges. It is not always easy to refuse them without the risk of undermining acceptance and delaying the project, which may cost much more than the interchange itself. As a rule, on the French motorway network, access points on rural roads are spaced at distances of 10 to 30 km. On urban roads, they may be closer together but, for weaving safety reasons, they must be no closer than 1,000 m.

On roads where long-distance traffic is not given priority over short-distance traffic, and where there are considerable access and interchange movements, the general rule is to provide at-grade T-junctions. If these junctions are saturated, grade separated junctions may exceptionally be justified. No formal rules exist for distances between ordinary at-grade junctions (T-junctions). However, it can be considered that a distance of less than 250 m will prejudice conditions of visibility, clarity, sign understanding and manoeuvre anticipation. It prevents overtaking and in general, has a negative effect on safety. French design rules recommend the spacing given in table 13. The question of roundabout spacing is slightly more complex. Such intersections, irrespective of traffic- or congestion-related delays, result in a geometry-related delay from having to traverse the junction. This delay can be estimated at 12 seconds on average for light vehicles. From this point of view, and also because their investments and maintenance costs are higher than those of ordinary at-grade intersections, it is not recommended to overmultiply roundabouts on a route. However, roundabouts perform well safety-wise and where there is heavy secondary traffic, they are a good solution in terms of capacity. Furthermore, if they are suitably positioned, they can help to mark the limit of change of the characteristics and quality of service of a specific route (change in cross-section, design speed or entrance to a built-up area, for example.).

Table 13: Distances between ordinary at-grade junctions (Reference France)

V 85 **(in kph)**	**60-70**	**80-90**	**100-110**
Minimum advisable spacing	600	900	1200
Overtaking capacity	300	450	600

Junction types

As a rule, the choice of junction types is instrumental in marking the identity, and consequently, the "legibility" of a road. On motorways, motorists expect grade-separated intersection, however on main roads whose role is for local traffic these will be the exception. It is therefore not recommended to use different types of junction over a route as it may confuse users' perception of the service level and prejudice their safety. This is particularly true when an at-grade intersection, even a roundabout, is installed on a section with grade-separated junctions. The quality-of-service requirement is thus to make junction types consistent with road types, in a manner that is clear to the user. When the junction category (grade or grade-separated) has been determined, there remains a possibility of choice that may affect the quality of service. This effect is marginal for grade-separated junctions but it may be more significant for at-grade intersections (ordinary junctions or roundabouts). The choice of junction type will be guided by considerations of safety, cost, capacity and time loss. Also to be taken into account are environmental and maintenance considerations, as roundabouts offer an area that can be remarkably enhanced by landscape planners.

III.2.12. Ancillary areas

Associated quality objectives.

The associated quality objectives are those of comfort, service to users, and safety. Some ancillary areas can also help to promote a region's activities, and a general economic concern in terms of investment, maintenance and operating costs is naturally involved in the choice of spacing and types of service areas. For instance, a pair of rest areas, each with a capacity for 15 light vehicles and 5 heavy vehicles, cost an average of F12 to 15 million on the French toll motorway network. With higher capacities of 40 light vehicles and 15 heavy vehicles, plus picnic facilities, games, toilets and telephones, the cost is F18 to 24 million. A pair of service areas cost between F25 and 35 million.

Spacing and equipment of ancillary areas

It is usually decided to install ancillary areas on a route out of a concern for a high quality of service owing to the amount of through traffic, which increases the probability that users will need to stop and rest or use certain services. In this respect, motorways, especially toll motorways which must develop customer loyalty, offer the highest level of comfort, often with well-equipped service areas. In recent years, services areas on the French motorway network have made notable quality-oriented efforts, with strict performance monitoring (quality charters).

The distance between these areas provided by French design rules is a maximum of 15 km (all areas) and 45 km (service areas) if the traffic is ultimately to be heavy. It is respectively 30 and 60 km if the traffic is light. In the latter case, it is also possible to maintain spacing of 45 km with two-way traffic.

However the road is not a world of its own, and when the traffic level does not warrant sophisticated service areas, it is always possible to encourage users to satisfy at least some of their expectations outside the road domain. For example, in return for some compensation, (attractive prices, later opening hours, clear information on services and how far they are), motorists are usually willing to go 2 or 3 kilometres out of their way to a village, providing they have been able to anticipate their decision early enough from specific signing. There are bound to be more urgent requirements which cannot be put off, for which a minimum number of facilities, such as refuges, must be provided right at the roadside. Qualitative surveys on users are highly instructive on this subject (VI.2.2).

In the United States, comprehensive service areas that have food and fuel facilities are generally provided only on toll roads. On the free Interstate system roads, however, only rest areas are provided. These rest areas, intended as short term stopping points, provide only parking areas, information and toilet facilities and do not have any fuel or food service facilities. The intent of the U.S. Congress in its enabling legislation for the Interstate System was to avoid creating governmental competition for the private sector and to rely for fuel, food and lodging on the private commercial operators at interchange locations.

III.2.13. Guidance systems

Associated quality objectives

Guidance of users is one of the essential dimensions of the quality of service, which in the years to come, together with the concept of the intelligent road, will revolutionize their behaviour. The associated quality objectives are obviously reduced congestion, increased capacity, safety, and driving comfort, and a reduction in negative environmental impacts.

Quality-of-service functions and criteria

There are many real-time information systems and research projects on Advanced Transport Systems (ATS). The aim here is not to describe them, especially as the subject is already covered by specific PIARC publications by group G3. These publications give a functional description of ATS systems, which are summarized in table 14.

Table 14: Functional description of advanced transport systems (Reference PIARC)

Travelling and transport management	Traffic control Incident management Road guidance Pollutant emission control and abatement In-transit information for drivers Information on services to travellers
Trip demand management	Demand management and processing Booking and car pooling Pre-trip information
Public transport management	for future reference
Electronic payment	Electronic payment service
Commercial fleet management	Electronic border control Automated security inspection Administrative control of commercial fleets On-board safety monitoring Commercial fleet management Hazardous materials incident warning
Emergency management	Reduced incident handling time Emergency calls and individual safety
Advanced vehicle control and safety systems	Avoidance of lengthways collisions Avoidance of side collisions Avoidance of collisions at junctions Improving vision to prevent accidents Safety checks on the state of the driver, vehicle and road Development of pre-accident protection Automatic motorway systems

These services use advanced technological elements for which it is essential to ensure interoperability. Beyond the purely technical feasibility and reliability aspects, a number of more general problems subsist in implementing ATS systems. These were outlined by the G3 group at the Congress of Montreal. They concern standardization, legislation, institutions, financing, and also drivers' acceptance of the system. User acceptability is clearly not just a problem of protecting privacy but above all, of accepting the price to be paid, as regards both the original equipment of the vehicle and the use of the service. This will probably mean that, at least during the period of developing and appropriating these services, they will only be implemented for certain types of users (commercial vehicle fleets, professional users), who are most able to gauge the financial return (e.g. reduced travelling time). This should also cause these services to be introduced on the roads most able to maximize the rate of return. The networks which best lend themselves to ATS services, besides the networks of major metropolitan areas which are faced with an increasing demand for travel, are the major arteries, interurban motorways with the heaviest traffic, and more particularly, those on which the motorists is willing to pay a toll. Moreover, it is these motorways which concentrate the heaviest spring and summer migrations of private users, for whom modern telecommunications and information technologies can provide valuable travelling assistance.

III.3. Service quality indicators associated with the intrinsic quality of the road

In section II.1, technical quality of service was described as being related to the supply, i.e. the technical measures taken by road owners, designers and operators in terms of intrinsic road characteristics, on the one hand, and the associated services such as maintenance and operations, on the other hand. The intrinsic quality was examined in section III.2. The aim now is to briefly outline the problematics of the quality of the associated services, given that the service level of road management has been addressed in specific publications for the work of PIARC Committee 6. The following sections will therefore be limited to underlining essential points on the link between the design and the management of a road. It will be further considered in sections V.1; VI.2.1; VI.2.2; VIII.1.

III.3.1. Ancillary services associated with the basic road functions

These are services not strictly procured by the infrastructure, which help to improve users' safety and comfort, such as phone facilities, facilities for procuring fuel and sundry purchases, catering facilities, breakdown services, rest facilities and the provision of information (IV.2.3).

On roads with rest areas, these services are usually all together. Naturally, the level of equipment of rest areas depends closely on the road type (III.2.12 b). Users greatly appreciate the security procured by the certainty that they will be able to use a particular motorway service, particularly in an emergency. On other road types, when they do not wish to drive as far as stop-over towns which have all kinds of services, oil company service stations, where they exist, usually offer the minimum services required by users (fuel, toilets, emergency repairs, supplies, telephone). However, these service stations are not so regularly spaced and do not necessarily meet such strict specifications as on motorways, particularly as regards opening hours. Users are thus not so certain of being satisfied in their expectations, and indeed, their safety.

Other possible alternative concepts to service areas have been developed, particularly by France, for roads isolated from their surroundings. They include the idea of ancillary village areas, which, as their name implies, require the motorist to go out of his way. Another concept is that of interchange zones, located outside the motorway domain, but which do not require him to go out of his way. Besides providing an interface between the motorway and the other transport networks, these zones offer various service functions. All these alternatives have the advantage of enabling various different funding arrangements, such as local authority contributions.

For services associated with the basic road functions, qualitative surveys will need to be made on users' expectations, and the supply will be gauged accordingly (IV.2.3). From the strict point of view of the existence of the supply, one of the important points to emerge from surveys on users (VIII.1) is that they expect their uncertainty to be lessened, through the supply status on the one hand, and through the knowledge they have of it by the information provided, on the other hand. For road designers and operators, this may be a discriminating criterion for the ranking of service levels associated with the basic road functions.

III.3.2. Maintenance service

Associated quality objectives

The basic aim of road maintenance is to maintain the technical performance of the infrastructure and its facilities. For road network managers, this mainly means preserving users' safety and comfort, reducing transport times and vehicle operating costs, and protecting the environment. However, users are not the only beneficiaries of maintenance work. The conservation of road assets (sustainability of technical supply), reduced maintenance costs, the safety of the road service staff, and the image of the road, are the constant concern of road owners and operators.

Quality-of-service criteria

The evaluation of maintenance quality refers initially to criteria of results, from the point of view of the user, the owner and the operator. For the latter two, the criteria to be taken into account are diverse and closely linked to road maintenance policies, information systems and especially to user monitoring systems and tools for measuring objective data on the condition of the roads, roadside areas and facilities. A common denominator in all these concerns of road managers is increasingly that of cost-cutting and making maintenance tasks cost-effective by adjusting them to the beneficiaries' strictly necessary requirements and by making rational use of the available resources. This is justified by increasingly heavy economic, budgetary and environmental constraints and by the continually increasing requirements of users.

There are many different maintenance tasks, which impose heavy responsibilities on the maintenance practitioners. In addition to meeting the challenges of road asset preservation, safety, comfort, and environmental protection, these people form the actual road image as perceived by users. Moreover, the users know this and though they may sing their praises, they are just as likely, and increasingly so, to initiate proceedings which can be legally damaging to the liability of these practitioners. But their judgement is relative as it does not necessarily differentiate between positive road performance which results from its intrinsic characteristics, and that which is specifically due to maintenance. In fact, if we confine ourselves strictly to the results of maintenance operations, it is dissatisfaction which is more perceptible because people notice when things work badly more than when they work well, which they consider as virtually normal.

This means that an important quality-of-service criterion on the road will be the absence of deficiencies perceptible by users. This again shows how necessary it is for them to make known their expectations and it requires road managers to be able to identify the relevant indicators of the road condition and set up measurement and analysis tools that will anticipate potential deficiencies so that they can be prevented before they occur. If they do occur, accidentally or through excessive use, the managers' capacity to correct them is in itself a quality criterion.

The financial resources allocated to maintenance are usually proportional to the classification of the networks and the size of the areas concerned. Clearly, motorways cost more to maintain than do ordinary roads. At the same time, some maintenance deficiencies (e.g. delayed intervention), which cannot be tolerated on motorways owing to the amount of traffic and the travelling speeds, are accepted more easily on ordinary roads. For given resources, and with reference to the service level objectives, two main types of criteria for the ranking of levels of maintenance service, can be distinguished in the experience of the different countries:

- "Space" criteria, which enable priorities for levels of maintenance service to be determined (i.e. for landscape maintenance in France: high-grade, regular and simple) depending on the areas concerned (for the same example: service areas, verges, surplus land),

- "Overall quality-of-service" criteria, which depend on the typology of the network and on priorities for the road's overall quality-of-service objectives (IV.2).

<u>The working margins of road network managers to optimize quality</u>

On an existing network or road, to reduce maintenance costs and, in general, to facilitate maintenance (including safety for maintenance workers) a number of conditions must be met, which will be examined in the following sections. But this requires maintenance concerns to be well-integrated into technical road practice and the design stages of a road. It is during these stages, through the choices of road layout and project design, that the future maintenance costs are committed. It is therefore highly desirable for road managers to be stakeholders in the design process and to give their opinions on the measures taken by designers and architects. Their opinions may concern geometrical provisions liable to affect the ease of maintenance, just as much as the choice of equipment or materials. In the final design stage, it is also advisable for the handing-over of the works to the operator to be accompanied by maintenance documents containing the as-built drawing and setting out the scheduled maintenance tasks and the frequency of maintenance operations.

During the lifetime of a road, the road network managers' leeway for optimizing the quality of service depends on many different parameters: service level objectives, road condition, traffic forecasts and, naturally, the available resources.

The guidelines for service level objectives are theoretically specific to a road type. However, for both motorways and ordinary roads, the manager is always at liberty to adapt the service level to the relevant space (III.3.2 b) and to the relation between this space and the user as regards both perception and solicitation. The levers available to road managers will obviously only work insofar as he has good information on the condition of the road and the use made of it. Qualitative surveys (satisfaction barometers) and behaviour studies provide additional input to more objective data collection.

As regards the resources allocated to network maintenance, which are likely to affect the final result in terms of quality of service, it is not enough to consider financial resources alone. The tools available to managers (e.g. to evaluate pavement condition and predict changes in behaviour, to simulate the medium and long-term effects of various maintenance strategies, to programme work on pavements, to accurately define maintenance on a road section) provide valuable help in selecting different maintenance options. The organization in place, the availability of technical reference systems, the availability of real expertise, the application of quality approaches, maintenance plans, and route-based maintenance charters, will ensure greater efficiency and better results. This is true not only for the technical aspect but also for the rationalization of budgetary resources.

As regards the influence of programming on the final quality, a distinction should be made between preventative and curative work. Admittedly their financial implications are not of the same magnitude, because preventive work is linked to an asset conservation objective and is usually more costly. But for such work, unless traffic trends exceed forecasts, it is always possible to postpone it for a year or more, without this having any serious impact on the way users perceive the quality of service. Curative work tends to be more urgent because it affects the user more directly, whether the problems concern safety, comfort, the environment or the road image.

Another factor to be considered when reflecting on how to optimize the quality of service concerns progress and technical innovation. Equipment, materials and methods are constantly undergoing improvements that increase performance and lifetimes, often at extremely competitive costs compared with older products. Conversely, the increasingly sophisticated (and even not-so-sophisticated) equipment now available, gives rise to extra maintenance costs. It is up to the manager to make extremely clear-minded use of anything new on the market. In this respect, the technical networks of the road administrations have a role to play in terms of training, assistance and advice as well as traffic control.

One last point not to be overlooked is that progress as perceived by the user may give rise to inflationary responses, for if he considers something to be good somewhere, he is surprised not to find it elsewhere. It may also be difficult to curb enthusiasm for materials or equipment because of the commercial pressure exerted by companies.

III.3.3. The operating service

Associated quality objectives

Road operations mainly cover three areas: road serviceability, traffic management and travelling aid. The associated quality objectives are safety, comfort, reduced congestion, an increase in the capacity of the roads and environmental protection.

Quality-of-service criteria

Road operations, like maintenance, form an essential dimension of the quality of service. The reports published by PIARC on this subject show that although much progress has been made in most highly-motorized countries and there is still considerable scope for change, not only because of the inevitable expansion of modern technology, but also because of the possibility of re-orienting new infrastructure construction. Moreover, on some existing roads, land and environment constraints are such that it is no longer possible to act on the physical parameters of the road. At the same time, road users are increasingly eager for mobility and are intolerant of the slightest malfunctioning, refusing to put up with any road blockages, and demanding free traffic flow whatever the weather and the circumstances. This makes it necessary to improve capacity and traffic flow, through various traffic-management-related measures such as controlled access, lane allocation, electronic fee collection and alternative routing. It also requires better incident managing, better co-ordination of roadworks, better regulation of freight transport. Above all, travelling assistance is at the beginning of a new era, as the status of today's technology already permits dedicated communications with users – or between users, the vehicle and the infrastructure (III.2.13), which provide better information on traffic conditions and better guidance for travel.

The tasks of the operating services are generally adapted to service levels conditional on the road typology and the intensity of traffic. Obviously, the heavier the traffic (particularly on urban expressways or interurban motorways) the more justifiable it is to set up efficient, often high-cost, operating systems in terms of staff (stand-by for emergency duties) and equipment for which maintenance must be provided. France has thus defined four possible operating levels for its national road network in interurban areas (VIII.1). Toll motorway concession companies have also developed efficient operating systems to guide and inform users. From the point of view of the technical supply, an evaluation of operating quality could thus simply be based on indicators of means (periods, frequencies, time horizons, intensity of work operations). These indicators are obviously not sufficient to judge overall performance, which will be examined later in this paper (see section IV) and will make reference both to objective and quantifiable results (e.g. decrease in injury accidents, traffic congestion hours, trip times, vehicle usage costs, pollution costs and also effects on users' behaviour) and from a more subjective point of view, to the qualitative expression of users' levels of satisfaction (see sections VI and VII).

IV. OVERALL QUALITY OF SERVICE OR OPERATIONAL ROAD PERFORMANCE

IV.1. Definition of the overall quality of service

In section II.1, technical road quality was described as being the technical measures taken by road owners, designers and operators to meet users' expectations. The overall quality of service integrates the "beneficiary" parameters and takes into account the operational performance of the technical supply in relation to the basic quality-of-service objectives. There are several indicators able to translate these results. In addition to the indicators most often referred to and used by the various countries, we will examine those which, because they are cannot be separated from users' perception and behaviour, correspond to the quality-of-service objectives contained in Table 1 (p 15).

IV.2. Indicators of the overall quality of service

IV.2.1. Safety

Safety is a particularly sensitive and important subject. Accident reduction is often a national objective and can be a significant factor in the monetary evaluation of the project, in which high financial values are attached to accident costs. Users can be many and varied including, in some cases, pedestrians, cyclists and horse riders in addition to vehicle traffic. The safety of all these user groups is often included in the overall evaluation of safety and it can affect the supply of service. In this field, the performance indicators that take users into account tend to be well known. Statistical studies and safety diagnoses are based on accident data or sometimes on the study of the behaviour of users, including the observation of near-miss accident phenomena.

As a rule, the safety performance of the different road types is well known from a structural point of view. Obviously the average safety performance level on motorways cannot be put on the same theoretical footing as that on ordinary roads. The important thing is to be sure which types of users are concerned by this performance level. Everyone knows that it is highly dangerous, and therefore often prohibited, to walk along a motorway. The figures in table 15 (p 85) give an example of these performance levels taken into account by France in its economic calculations. However they cannot form a prior criterion for deciding between two road types that do not meet the same expectations, or the same constraints, in terms of land use planning, capacity, free traffic flow, environment and financing.

Table 15: Safety indices taken into account in economic calculations (Reference France)

	Accident rates per 10^8 veh km	Fatalities per 100 accidents	Serious injuries per 100 accidents	Slight injuries per 100 accidents	Hazard cost F/veh x km
< 7 m	19.1	17	58	110	0.18
7 m	16.5	19	61	110	0.17
3 lanes, 10.5 m	12.4	23	62	108	0.15
4 lanes	13.8	18	45	118	0.13
2-lane dual carriageway	9.6	21	67	102	0.11
motorway	7	11	30	120	0.04

On existing roads, accident cluster areas are a hazard indicator and reveal malfunctioning of the infrastructure. The criterion for identifying these areas should be solely that of risk. This entails identifying the places that have a significantly higher accident rate than the mean accident rate for places with the same characteristics. Admittedly, it is not always possible to obtain significant results, and that is what makes safety studies so difficult. It may be tempting to question users and take their point of view as a safety indicator, or to observe quasi-accident phenomena, such as conflict areas at intersections, which will also be taken as hazard indices. But all these indicators must be used carefully because there is not always a correlation between people's declarations and the objective hazard findings based on accident data.

IV.2.2. Travelling comfort (reducing inconvenience and increasing trip reliability)

Individual comfort is a subjective concept which affects an individual's physical and mental state. For the user, the example can be the physical sensation caused by the pavement surface condition or the sensation of stress or irritation caused by traffic density. Users' fatigue is also an important factor to be considered because it closely affects their vigilance and ultimately their safety. These elements will be studied in the section on users' perception and behaviour.

Beyond individual comfort, a more macroscopic approach, concerning not individuals but a body of users forming the traffic flow, gives another vision of comfort, which is that of "traffic comfort". Traffic comfort can be characterized by several indicators reflecting the levels of inconvenience confronting user populations. The following aspects are among the most usual, in the case of a trip on a link section:

- uninterrupted or interrupted traffic flow,
- mean trip speed,
- speed in free-flowing traffic,
- density of traffic flow,
- the speed/capacity (v/c) ratio between the flow during the 15 peak minutes and the maximum permissible flow corresponding to the capacity,
- loss of time in vehicle queues,
- space and time between vehicles.

Mean trip speed and speed in free-flowing traffic

The indicators may differ, depending on whether or not the infrastructure planning characteristics, at junctions for example, give rise to traffic interruptions. It is interesting to examine a few of these indicators in detail, beginning with speed. The HCM defines several speed concepts, among which is the mean trip speed. This is an important indicator of the quality of traffic flow, which is easily measured by observing individual vehicle speeds. Another concept is speed in free traffic flow. It corresponds to the theoretical traffic speed when traffic density is close to zero. In practice, this speed corresponds to the speed at which drivers have an impression of comfort when travelling on a road with a low level of traffic. In fact, this speed remains unmodified within a wide range of hourly traffic flow.

Traffic comfort criteria on freeways (according to the HCM)

On freeways, for example, a free-flow speed of 110 kph can be maintained up to a flow of 1,300 light vehicles per hour and per lane (1,300 lvphpl). A lower speed can be maintained up to still higher flows: 1,750 lvphpl for a speed of 90 kph. The free flow speed is influenced by various factors such as: design speed, frequency of ascending gradients per km, complexity of the driver's surroundings, speed limits. And this free-flow speed has a definite impact on the mean trip speed on freeways. But this does not mean that it is an adequate criterion for qualifying infrastructure operation, owing to its lack of sensitivity to different flow levels. However, any section of freeway can be characterized by a free-flow speed curve similar to the curves determined in the HCM. It is then possible to take account of another important indicator of overall road performance, which is traffic flow density. This indicates freedom of manoeuvre in traffic and headway between vehicles. For different free flow speed values and ideal conditions on freeway link sections, the 1997 updated HCM the relationship between the service level class (from A to F) and the maximum density, together with the minimum speed, maximum service flow, the *v/c* ratio between the 15-minute peak flow and the maximum permissible flow corresponding to the capacity. For a free flow speed of 110 kph, we obtain the following results:

Table 16: Correspondence between service levels and performance indicators (Reference USA)

Service level	Maximum density (lv/km/lane)	Minimum speed (kph)	Maximum service flow (lv/h/lane)	Maximum *v/c* ratio
A	6	110	660	0.28
B	10	110	1,100	0.44
C	15	109	1,635	0.66
E	20	101	2,020	0.84
F	28	84	2,350	1

On the basis of these results, for "ideal" conditions, it is possible make adjustments to the maximum service flow to take into account lane widths and side clearance, the presence of heavy vehicles, buses and leisure vehicles, gradients, and users' familiarity with the site. The HCM provides all the adjustment tables.

Traffic comfort criteria on the highways (according to the HCM)

On highways as for freeways, the same phenomenon of free flow speed stability is observed. Whether on 4 or 6 lanes, divided or undivided, with a speed limit of between 65 and 90 kph, the free flow speed can be maintained up to a flow of 1,400 lvphpl. The free flow speed is also used as a basis, together with the traffic flow, for calculating traffic density which, as on freeways, defines the service level. Adjustments can be made to the free flow speed estimated for ideal conditions to take into account divided and undivided carriageways, lane widths, side clearance and density of access points. Two adjustments can also be made to the flow. They concern peak hour factor (or flow variation during the time covering the 15 peak minutes) and the equivalent number of light vehicles. This calculation is based on the slopes and gradient lengths and on the percentages of lorries, buses and leisure vehicles. The service level can be directly inferred from the tables and charts in the HCM.

Traffic comfort criteria on 2-lane roads (according to the HCM)

For 2-lane main roads, the quality of service of traffic flow as determined by two indicators: mean travel speed and loss of time in vehicle queues. This is because on these roads, lane changes and overtaking are disturbed by oncoming traffic. The observations made on the North American network have demonstrated that speed is not greatly affected by traffic volume – between zero traffic and 3,000 lvph, the mean speed decreases from 95 to 70 kph. The loss of time in traffic queues is the average percentage of the total travelling time spent by motorists in traffic queues, with inter-vehicle time intervals of less than 5 seconds and speeds lower than the desired speeds. This loss of time reflects a reduction in the quality of service perceived by the user. It can be estimated according to the traffic volume.

IV.2.3. Services to road users

Performance indicators of services offered to users obviously depend on the type of service. Only services ancillary to the basic road functions are taken into consideration here. These ancillary services can include:

- phone facilities,
- facilities for procuring fuel and sundry purchases,
- breakdown services,
- emergency assistance
- catering facilities,
- emergency stopping facilities
- rest facilities,
- entertainment facilities,
- the provision of information (weather forecast, congestion, accident, services).

For these services, the most commonly used quality indicators result from surveys on users (see section VI.2). They give a qualitative assessment of the way users perceive the quality of the services. However, road operators may use more quantitative criteria which enable them to compare the service demand to supply. They can thus determine the avenues of progress to be explored to give greater satisfaction to users. These criteria can include:

- response time of emergency services,
- rate of use of services in proportion to traffic on the road in question,
- user satisfaction rates with respect to the various services,
- waiting times at service stations,
- waiting times after a breakdown,
- car park occupation rates on rest areas during peak days,
- cleanliness indices of rest areas.

IV.2.4. Integrating the road into the human environment

Environmental appraisal

The environment is also an important, sensitive subject in relation to road projects. In this paper, the word "environment" is given a broad interpretation that takes into account all the effects of the project which go beyond the immediate surroundings of the road. It is usual that discussions on road projects are obliged to address local and general social considerations. The corresponding issues cannot usually be resolved within the scope of the road project alone but they often contribute towards higher-level objectives. For these reasons, the environmental effects are often considered in terms of a high number of effects or impacts.

During the road designing stages, steps are taken by the owner and the designers to limit the impact of the road on its environment. It is natural, sometimes mandatory, and at all events highly recommended, to check the results of these measures once the infrastructure is in operation. Several countries have introduced monitoring systems and environmental appraisals. These measures have a cost and are not without political implications. For example, in France an *a posteriori* environmental appraisal is mandatory for road projects, just as there exists an economic and social appraisal for projects exceeding a certain financial value. These appraisals must be made under the owner's responsibility. After the government's environmental commitments have been made known, compliance with them is controlled and the real effects of the works are evaluated after a certain lapse of time. The environmental appraisals must take into account not only the permanent effects but also the indirect and temporary effects of the road improvement. Environmental appraisals must be made in close conjunction with an analysis of the economic and social repercussions of the road improvement. Among the appraisal themes more particularly concerned with impacts on the human environment are those listed in Table 17 (p 93).

Criteria to be taken into account (see Table 17)

In an evaluation of road service quality, criteria must obviously be chosen to be representative of the actions by owners to improve the existing situation or limit negative consequences on a particular aspect of the human environment. This requires sufficient data on the situation before beginning the project and clear objectives in terms of efficiency of prevention measures or the installation of protection systems. It is particularly important for noise, water pollution and atmospheric pollution. Another aspect to be taken into account is that what is good or bad for the environment can vary considerably from one country to another depending on the socio-economic conditions.

Table 17: Criteria of integration into the human environment (Reference France)

Subjects of evaluation	**Criteria to be taken into account**
Physical environment	Microclimate change; air quality change; change in ground stability and induced erosion; evaluation of the benefits of an improvement in overall pollution control; evaluation of natural resources that are non-renewable, eliminated or made unusable.
Ground water	Evaluation of geological changes in land use; new conditions of water table use; change in the physico-chemical quality of water and efficiency of protection systems; change in the bacteriological quality of water and efficiency of protection systems; change in human use of ground water
Surface water	Change in the hydrographic situation; change in new hydraulic conditions and in their consequences on farming activities and on urban planning; change in the physico-chemical quality of water; change in the human use of water.
Agriculture	Change in agricultural development resulting from the road improvement; change in land use; land reallocation.
Forestry	Capital or resource losses; consequences of changes in the organization of woodlands; evaluation of forestry development revision; situation of forestry estates.
Heritage	Enhancement of the architectural heritage; enhancement of the archaeological heritage, ethnological heritage, heritage creation.
Urban planning and land use	Change in the distribution of urban development and industrial activities; changes in urban planning documents; locations of, and recent changes in living and service centres; changes in travelling patterns.
Recreational use of land	Change in recreational use; impact on hunting and fishing.
Noise	Changes in noise levels; efficiency of protection systems; protection during site work; satisfaction of residents; integration of noise into land use plans.
Psycho-sociological aspects	Changes in the way people feel towards the infrastructure.
Technological risks	User safety; safety of property and people close to the road.

Note that France has adopted monetary values of air pollution effects and the greenhouse effect for the cost-benefit analysis of its road investments. And the Norwegian Road Administration has devoted considerable efforts to finding methods and procedures for evaluating the impact of road projects in monetary terms.

IV.2.5. Integrating the road into the natural environment

The evaluation method can be the same as for the human environment.

Table 18: Criteria of integration into the natural environment (Reference France)

Subjects of evaluation	**Criteria to be taken into account**
Natural environment	Change in plant community coverage; change in plant types; disappearance of plant communities or species; introduction of new species
Wildlife	Change in habitat, in groupings of wildlife or species, evolution of species; death rates; physical containment; use of animal crossings.
Landscape	Changes made to protected sites by the project; changes made to other sensitive landscapes by the project.

Whereas impacts of the road on the human environment, such as noise or air pollution, can be given monetary values, its impacts on the natural environment are primarily measured in qualitative terms, even though quantitative criteria may sometimes be used, for example, for counting plant or animal species.

We cannot fail to mention in this respect some of the many landscape improvement experiments, such as those in the United Kingdom, Norway, Denmark and the United States.

IV.2.6. Access to urbanized areas and to activity areas

The evaluation criteria of a road's quality of service are both quantitative and qualitative. The owner will use quantitative criteria to ensure his goals have been achieved, by comparing traffic indicators with his forecasts or projections (through-traffic, local traffic, origin/destination, heavy vehicle traffic). Comfort indicators relating more particularly to the functioning of junctions are also valuable. Classic examples are vehicle density on entry or exit ramps, and mean vehicle speeds on these ramps (see the HCM) for roads with grade separated junctions. For roads with junctions at grade, waiting times provide a good indication of how a junction operates, and consequently of the performance of service roads. In terms of quality indicators, information on access to activity areas is mainly gained from surveys on users and residents. Consequently, any political or social pressure to improve access to an area must be considered as a signal which obviously needs careful analysis against the main functions allocated to the road by the owner. Where the road is an arterial, it is not desirable to add road junctions that are liable to generate extraneous traffic. In any case where it is an ordinary main road, for reasons of safety and comfort, it is not advisable for junctions to be too close together.

IV.2.7. Supporting and encouraging regional activities

It is an accepted fact that transport infrastructure has favourable effects on social and economic activities, but in practice it is rather difficult to quantify the real effects as not many *a posteriori* evaluations have been made on the subject. Conventional cost/benefit analyses cannot satisfactorily account for the effects of a road on economic development and in-depth micro-economic studies must be made in addition to traditional evaluations on economic and environmental impacts. France has recently published the findings of "economic monitoring" studies aimed at evaluating the spill-over effects of major highways on the regions they cross. Without repeating in detail over the information already given in the World Road Association's magazine, it will nonetheless be useful to consider the evaluation criteria used by its authors. Table 19 summarizes the indicators used to evaluate the effects on businesses, and the main results for roads with motorway status or 2-lane dual carriageways with grade separated junctions and controlled access.

Table 19: Example of evaluation criteria of economic impact (Reference France)

Evaluation criteria of economic impact	Main findings
Transport cost	Average reduction of 15 to 20%
Transport demand	Significant increase
Improvement in accessibility	
Markets	Extension of market sites and growth of the market
Competition	Intensification and strengthening of primate centres
Effects on company reorganization	Possibility to develop "just-in-time" Decentralization of storage areas
Employment resulting from motorway operations	3 to 4 jobs per km of motorway
Locations of activities and jobs	Strengthening of linkages
Job changes and spatial distribution	Accentuation of existing potentialities

IV.2.8. Enhancement of the overall benefits to users and public authorities

The monetary evaluation of the advantages to be gained from the infrastructure by users and public authorities is made when selecting solutions and comparing the competing projects. As most of the criteria used can be quantified from the traffic levels, it is always desirable to check the validity of forecasts or make new forecasts for the road in service, with a view to rehabilitation or renovation operations. If we refer to various countries' practices for allocating a monetary value to the advantages of transport infrastructure to users, the main criteria are usually the following:

<u>Time savings or losses</u>

Journey time is a determining choice criterion for the road user. This is obvious when he can choose between several modes of transport. It is also true when he chooses to use the motorway rather than an ordinary road to get from point A to point B. The journey time is the sum of time spent travelling in free flow conditions plus times in queues of vehicles, plus stopping times for various reasons whether ascribable to the user (for relaxation or a service) or otherwise (roadworks, bad weather conditions, accident, congestion).

The journey time criterion is consequently not unrelated to other traffic comfort indicators considered in IV.2.2. Savings in time have a monetary value, which is included in the calculation of the advantages offered to users by a road investment. In principle, it is acceptable to determine the time value differently when the customers are different. For example, Norway recommends monetary values varying from 85 to 198 kroner per hour for light vehicles and a constant value of 272 kroner per hour for heavy vehicles. In France the values for these two vehicle types are respectively 74 and 193 francs per vehicle and per hour. The latter two examples reveal differences from one country to another. A European study has been initiated on the valuation of time savings, which particularly aims to examine the reasons behind these different values between countries in Europe.

Italian experience of the study of monetary value of in-trip waiting time includes a calculation model for congestion costs evolved by the Autostrade Company, which measures the impact of phenomena liable to affect trip times (accidents, roadworks, heavy traffic, inclement weather). The model, which is still in the form of a prototype, measures the magnitude of these phenomena. It is based on indicators for making comparable syntheses in time and space in order to check variations and determine improved solutions. These indicators, usually defined as **time losses**, have two main areas of application: the asphalt motorway strip and the toll stations.

To calculate time losses, two quite complicated mathematical models are used:

- "TURBATIVE" to evaluate time losses over a route and determine the main causes (heavy traffic, roadworks, accidents),
- "CASTORE" (VIII.1.3) to monitor what happens at toll stations.

The time loss indicators are the following:

- percentage of vehicles concerned out of all the vehicles in transit,
- time lost,
- kilometres travelled in queues.

The indicator for the vehicles concerned provides an evaluation of vehicles in queuing or slow-moving traffic, usually called "disruption", using a mathematical model.

The time loss indicator measures the time lost by all the vehicles involved in the disruption.

The indicator for the kilometres travelled in queues provides a forecast of the kilometres travelled by all the vehicles involved in disruption.

Based on the foregoing, a calculation model of congestion costs has been developed, which is still in the prototype stage.

The basic assumption formula for the calculation of congestion costs at toll stations and on the motorway network managed by the Autostrade Company is the following:

$$Cg = (C^* DT) + Df$$

where:

Cg **=** Total cost of congestion;
C **=** Cost of a time loss of one hour;
DT **=** Lengthening of trip time due to disruption.
This is given by the total number of lost hours less the total number of hours it would take to cover the same distance at average speeds in normal conditions;

Df **=** Increase in petrol consumption.
This increase is given by the consumption of vehicles in slow-moving traffic less the consumption of the same vehicles in normal traffic conditions over the same distance.

The value of a time loss of one hour per vehicle is calculated using the following formula:

$$C = V^* (P1 + k * Ps) * cp$$

where:

V **=** mean associated value of a working hour;
Pl **=** percentage of customers using the motorway for work or for study;
Ps **=** percentage of customers using the motorway for different reasons;
k **=** ratio of the value of a non-working hour to a working hour;
cp **=** occupancy coefficient per vehicle

The mean associated value of a working hour is calculated by dividing the mean annual associated value (1990 value) per work unit by the mean value of the hours scheduled in the contract of each worker.

Conversely, the overall number of lost hours (Tp) is obtained by multiplying the number of slow-moving vehicles by the mean waiting time.

Improvement in comfort

In France, the unit value of the discomfort index has been determined, like the revealed time value, by analyzing the behaviour of users. This analysis has enabled a pair of values – time and discomfort index – to be determined. The presentation of the time advantages for users is consequently linked with that of comfort advantages. These advantages are expressed, solely for light vehicles, by unit discomfort index values, in F/vehicle/km.

Variations in vehicle operating costs

Journey times, road alignment difficulties, changes in slope compelling heavy vehicles to frequently change speeds, road surface quality, having to brake at approaches to overfrequent or overcongested junctions – all these factors may increase vehicle operating costs borne by users. These costs include various components such as regular maintenance, vehicle depreciation or fuel costs.

IV.2.9. Reducing the overall economic cost

Associated quality objectives

The overall economic cost is taken here as the discounted amount of expenditure on studies, land acquisition and work, to which is added the cost of major repairs. Internal or external social costs are not included. The associated quality objective mainly concerns owners or concessionaires who are aiming for the best financial result. This result can obviously not be dissociated from constructional measures taken by designers during the design stages, and the role of these designers in developing project quality (II.4). Neither can this result be dissociated from the perception of users who may react as taxpayers, or sometimes even as customers required to pay a toll, the cost of which will be all the higher where the overall economic cost itself is high.

Margins for reducing the overall economic cost: contributions of value analysis

In principle, there is a link between road types and the costs of investments and major repairs. In addition, for the same road type, the costs are based on the difficulty of the site (plain, rolling, mountainous). Most countries determine ratios which serve as a reference for designers and economists. Beyond these ratios, road project costs depend on many parameters on which designers can act, in the design stage, to reduce the investment costs. However, it must be borne in mind that many factors may also act the other way round, with a tendency to increase the project costs.

As previously stated, 70% of the cost of a project is committed at the time of drawing up the programme (or specifications) of a project, even before starting the design studies. This shows that specifying the programme requirements, which is the entire responsibility of the project owner, is a particularly important stage in the cost control of a project. But although owners have increasingly succeeded in developing survey, communication and consultation systems and policies, with a view to better understanding users' needs, this change is not without *quid pro quos*. The first is that going straight to the people means confronting increasingly complex realities in terms of user expectations and behaviour as well as the environmental, legal, political and social constraints surrounding road projects. The second is that when users, residents and elected representatives are aware that their opinions are valued, they demand to be consulted and above all, they expect concrete answers. Sometimes these answers will necessarily involve further costs, which automatically means an increase in the cost of the road project. Project owners must accordingly organize themselves and devote the necessary time and skill resources to drawing up the project programme. They must not only develop skills in the fields of future planning and communication, but also be capable of translating users' needs into functional project specifications, using the method of functional analysis. They must also be able to evaluate the target cost of the project. Lastly, not only project owners but also their engineers must take into account the progressive nature of programme development.

Although the owners' responsibility in controlling project costs is clearly apparent in the definition and management of a programme, in target cost fixing and more generally, in the reliability of his order, it does not detract from the project engineer's responsibility – quite the reverse in fact. The engineer's role is to give the owner a technical, economic and architectural solution or solutions for the project programme. He must also undertake to meet the target cost fixed by the owner. This may mean having to overcome something of a contradiction. The owner may legitimately be in favour of making more exhaustive definition studies and taking them further in the project process (for example as far as the choice of route layout) so as to achieve a sufficiently detailed programme and a reliable target cost. This does not in itself conflict with the subsequent commitments of the engineer. However, the latter may prefer to be involved earlier, say at the functional specification stage, even before the study and comparison of the alternative route layouts. The engineer's argument for being involved earlier, when the specifications are still quite open-ended, is that this gives him greater creative freedom, enabling him to offer the best, most cost-effective solutions for the specifications.

A good way to handle this contradiction is to link the owner's role (basic project objectives, functional expression of needs, definition of constraints, fixing target cost, consultation) with the engineer's role (the actual design, compliance with the target cost) around a value analysis process, before the route layout is chosen, i.e. during the study and comparison of the alternative layouts.

Once the main planning and development options, which will enable the engineer to begin the project design, have been defined, decided and explained, the engineer must undertake to respect the options taken by the owner, particularly the target cost. If new functions are added to the project, or if unforeseen constraints emerge in connection with the project, this must naturally result in a new order from the owner and the target cost must be revised. At all events, for the engineer to meet the owner's commitments, he must be competent and efficiently organized. It is particularly necessary to ensure efficient co-ordination of all the contractors (particularly consultant engineers) to achieve overall consistency of the project, both from a functional point of view and that of compliance with the total target cost.

In conclusion, the problem is not one of determining the overall cost reduction margins offered to road designers. The problem is for the owner to fix a reliable target cost from the start meeting the strict functional necessities, and for the engineer to meet this target cost by implementing the best, least expensive solutions consistent with the functional expression of requirements. The achievement of this two-fold ambition will depend mainly on the owner's and the engineer's organization and on a clarification of their respective roles formulated in quality assurance plans. This will make them better equipped to cope with project contingencies and to handle the technical, legal and financial risks, more particularly by shortening response times.

IV.2.10. Reducing maintenance and operating costs

Considerations on maintenance and operating costs have been developed in sections II.3.2b and III.3.3b.

In terms of performance, this aspect of the overall quality of service is closely related to the previous question of the overall economic cost, for if a reduction in this cost were to lead to an increase in maintenance and operating costs, that would defeat its purpose. Maintenance and operating funds are often more limited than investment funds and more difficult to obtain. Inadequacy of resources is bound to affect the quality of service and any deficiency in this respect is immediately perceived by the users.

V. MEASURING QUALITY-OF-SERVICE INDICATORS

V.1. Objectives in measuring the quality of service

Quality of service is measured in order to ensure that the technical service meets with the required level of quality, and to measure the actual results in terms of overall performance. Why measure the quality of service?

Clearly it is on existing roads that the measurement of quality of service takes on its full meaning, because measurement is made on a physical reality – the road network or the route. For owners, it is essential to measure the quality of service to plan investments on the various networks. This measurement provides road maintenance and operation managers with the necessary indicators for programming preventative or curative maintenance work and for organizing road operations. It enables them to better cope with changes in user demand. Generally speaking, owners and operators obtain helpful information from measuring the overall quality of road service, and maintenance practitioners from measuring technical quality.

The aims of the maintenance and operating services are:

- Technical quality of service:
  - ensuring sustainability of technical supply
  - maintaining the technical quality of supply
- Overall quality of service:
  - maintaining overall performance
  - influencing service demand

These aims must not be confused with the basic quality-of-service objectives given in table 1 (p 15). However, it is interesting to have an interlinked approach to both types of objective, in order to determine the possible aims of the measurement. An interesting element to be considered when analyzing links between both types of objective is the breakdown of the road into organic elements capable of focusing the attention of the maintenance and operation services. It consists in addressing those main characteristics in table 3 (p 27) most relevant to the tasks of the maintenance and operation services. Each of these characteristics is then examined in greater detail to see what quality-of-service measurements will help to achieve the quality-of-service objectives inherent in these tasks.

This comparative approach was developed in France within the framework of design, maintenance and operation charters on road and motorway networks.

The main characteristics to be taken into account from Table 3 (p 27) are as follows:

- cross-section
- junctions
- pavements
- service areas
- means of environmental integration
- road signs and safety, comfort and operation facilities
- engineering structures

For each of these characteristics, the road's basic quality-of-service objectives, such as those connected with safety, comfort and the environment, can be compared with the specific objectives of the maintenance services. This enables the purpose of the various measurements to be determined. Table 20 illustrates possible comparisons for the cross-section, and more particularly for the safety zone and the recovery zone (an example which can obviously be transposed to other major characteristics).

Table 20: Example of a comparison of maintenance objectives and quality-of-service objectives

Cross-section	**Purpose of quality-of-service measurements in relation to the objectives of the maintenance and operation services**			
Safety zone and recovery zone	Technical quality of service		Overall quality of service	
	Ensure sustainability of technical supply	Maintain technical quality of supply	Maintain overall performance	Influence service demand
Ensure safety	• Checking non isolated obstacles • Surveys on needs	• Checking performance of safety barriers • Checking structures and surface characteristics • Checking visibility	• Measuring severity of accidents due to running off the road	• Measuring skid resistance of adjacent pavements • Studying behaviour patterns
Offer travelling comfort	Checking side clearance			
Integrate the road into the human environment	Checking the existence of means of integration	Checking condition of roadside areas and functioning of the means of integration	• Measuring impact (water pollution, residents' perception)	
Integrate the road into the natural environment	Checking the existence of means of integration	Checking the functioning of protection devices	• Landscape condition. • Measuring impact on fauna and flora	

V.2. Scope of measurement

It is obviously impossible for this paper to review the conventional analytical measurement methods of all the quality-of-service indicators referred to throughout the previous sections. Our attention will primarily focus on macroscopic measurements, i.e. those made on routes or networks.

Except for rare systems of overall road performance quantification, such as the American HPMS (Highway Performance Monitoring System), experience in this type of approach tends to be restricted to a few major fields. In terms of the technical quality of service, the focus of attention is usually pavements. This is quite understandable owing to their importance in maintenance and asset preservation. Overall performance measurements mainly concern safety. Congestion is also a priority measurement owing to its economic implications and environmental impact (noise or pollution).

The qualitative evaluation of quality of service, based on surveys on users, is increasingly common (e.g. in France, United States, United Kingdom, Australia, the Scandinavian countries). It is most interesting for two reasons. It is consistent with the definition of quality as reflected in the capacity to meet the requirements of users. It is therefore natural to interview these users and other beneficiaries of road services. The aim is to better meet the expectations and needs they have expressed. These surveys also enable quality-of-service measurements to be extended to other fields such as road characteristics, ancillary road services or traffic conditions.

Lastly, it is important to evaluate, or rather anticipate the technical quality of service at the time of the road project work, during the design and construction stages. This may be in the form of internal or external quality controls or in the form of quality audits. They may be performed on specific aspects such as safety, the integration of environmental constraints or even the incorporation of maintenance and operating concerns into road project design. For example, in France, the *Comité Interministériel de la Sécurité Routière* (Interministerial Committee on Road Safety) has decided to set up road project safety controls. Most countries are in agreement on the definition of a project safety audit as a formal examination of project safety performance by a specialized team at different stages.

V.3. Examples of methods and tools for measuring the technical quality of service

Operations to measure road service quality require human and material resources for data collection and processing, which usually make them expensive. It is true that most countries have developed high-performance measuring systems such as those used for pavements, but they are not suitable for all road characteristics. It may be useful to make qualitative measurements based on monitoring and direct observation by skilled staff in charge of maintenance and operations.

V.3.1. Asset management in the United States

The U.S. has nearly 6,3 million kilometres of streets, roads, and highways and more than 550,000 bridges. These roads and bridges represent a Federal, State and Local Government investment of more than 1,000 billion dollars. They represent the Nation's largest government-owned asset and must be managed efficiently and comprehensively. Since 1996 the Federal Highway Administration (FHWA) and AASHTO have been promoting the use of asset management techniques to better manage these assets.

Asset management is a systematic process of maintaining, upgrading, and operating physical assets cost-effectively. It gives decision-makers ready access to quantitative and qualitative data enabling them to evaluate the state of an organization's available resources and the current and predicted condition of facilities. It clarifies decision-making on the basis on these data and on "rules of thumb" and principles drawn from engineering experience, economics, accounting, risk management, and customer service to ensure efficient resource allocation and asset optimization.

Asset management systems also benefit the users by providing:

- Improved convenience,
- Improved service (e.g., comfort, reliability, safety),
- Savings passed on from the owner operator of the road facilities to the customer,
- More accessible facilities and services due to more efficient operation (and, in the transportation context, less construction and maintenance disruption).

V.3.2. Pavements

There is no question in this section of encroaching upon the areas of competence of Committees C1 (Surface Characteristics), C6 (Road Management), C7 (Concrete Roads) and C8 (Flexible Roads). The aim is simply to highlight recent progress in measuring the quality of road service.

It must be remembered that service level objectives for a pavement are basically initial constructional options which integrate subsequent maintenance operations. It is mainly these subsequent operations that will motivate the quality-of-service measurement, with the central aim of maintaining initial performance as regards not only users, but also other aims such as asset preservation (maintaining the integrity of the structure) environmental impact, and compliance with initial maintenance strategies in the light of changing economic constraints.

The handbook "French pavement design method" adopts five groups of objectives in its analysis of the service provided by a road. Added to these objectives are various aspects affecting the final result (see table 21, p 117).

Table 21:
Quality-of-service objectives for pavements and related factors (Reference France)

Quality-of-service objective of the pavement	**Aspects affecting the final result**
Safety	longitudinal and transverse skid resistance longitudinal and transverse evenness surface water runoff time
Journey times and costs	maintenance work weight limits during thaw conditions
Regularity of the service	vertical accelerations caused by evenness defects and damage
Driving comfort	tyre noise
Trip comfort	visual comfort from surface consistency, colour and shine

The handbook stresses the difficulties in quantifying levels of pavement service, which include:

- the difficulty in finding measurable indicators for all aspects of the service level concept,
- the subjective character of the user's perception.

The document also describes how some countries have opted for an overall index of the level of pavement service, through correlating physical parameters, such as evenness and skid resistance, with the way users perceive them. The service level is rendered by a single numerical value.

In most states of the United States, the evaluation of pavement condition on the primary network is based on the International Roughness Index (IRI) developed by the World Bank. The FHWA has recognized it as being a more objective measurement than that of the PSR system (Present Serviceability Rating), which is nonetheless still used on the secondary road network.

In France, the evaluation of road condition is linked to an analysis of maintenance work requirements. The IQRN system (Image Qualité du Réseau Routier National - Quality Image of the National Road Network), developed by the Directorate of Roads, evaluates the condition of road assets and their patterns of change. Data are collected by high-performance equipment and a computer-aided system for gathering information visually perceptible by an experienced operator. They enable ratings of between 0 and 20 to be calculated over 200-metre sections, which are inferred from conventional rehabilitation costs. The results are presented as histograms that represent the condition of the road network.

As regards the safety aspect of quality of service, it is mainly the surface characteristics that are measured. Measurement methods for quantification correspond to the various aspects given in Table 21. Particularly relevant here is the work of Committee C1, which was reviewed at the Montreal Congress and consisted in taking stock of measurement equipment of surface characteristics and organizing an international experiment aimed at harmonizing the different methods used the world over to measure skid resistance and texture of road surfaces. It has given rise to a common scale of friction values, IFI (International Friction Index), in which all results of friction coefficient measurements on roads and aerodromes can be expressed with an accuracy of 0.03.

For the regularity of the service, the cumulated duration of interruption of traffic, whether for maintenance work or for weight limits during thaw conditions to preserve road assets, form a simple indicator, easily measurable, or predictable from maintenance scenarios and climatological probabilities.

Parameters affecting comfort, such as travelling noise, or longitudinal evenness which measures comfort related to transverse accelerations, can be easily quantified.

V.4. Examples of methods and tools for measuring the overall quality of service

V.4.1. Safety: checking road project safety

The French example

France has set very ambitious goals for reducing road hazards. The measures involved affect users' behaviour, vehicle regulations and infrastructure characteristics. As regards the infrastructure, the Directorate of Road Safety and Traffic has required a road project safety control to be introduced over the national road network, covering both major projects (new rights-of-way) and improvements on road sections or on particular points in the existing road system. The control procedures are being finalized. They apply to four major stages in the project process: pre-project studies, preliminary design studies, the project and the safety inspection before opening the road to traffic. At each stage, the safety control can be either internal or external. It is based on a reference system in the form of questions for each control phase on specific themes (junctions, interchanges, specific traffic conditions, etc.). Each question refers back to the supporting regulations.

In the planned organization, the controller, who will have received appropriate training for his task, must be independent from the project team and will report to the owner. Among the problems in implementing this scheme, is that of the legal liability of the controller. Moreover, it is this legal liability problem that caused France to draw back from another safety control scheme which concerned not road projects but the actual infrastructure.

The American example

For highway planners and designers, one of the most difficult tasks today is balancing the varying, and sometimes conflicting, project needs and impacts. The planner and the engineer are charged with providing appropriate level of quality in traffic service, operation and safety, and at the same time being sensitive to and meeting the goals and the needs of the community and the environment.

Because it designs and builds roads in some of the most critical of environmentally sensitive areas, the U.S. national parks, the Federal Lands Highways office of the Federal Highway Administration has developed guidance and procedures for analyzing the safety risks associated with road projects.

The guidance provides the planners and designers with a procedure and a sound technical basis for assessing the risk associated with design decisions involving the following highway features:

- Cross-section (lane and shoulder width).
- Roadside (side slope, fixed objects, and clear recovery area).
- Intersection Geometry.
- Horizontal Alignment.
- Vertical alignment (grade and vertical curvature).
- Stopping Sight Distance.
- Bridge Width.
- Interchange Design.
- Pavement Skid Resistance.

The risk is expressed in terms of an expected safety performance or operational performance. Table 22 shows what design items are assessed on the basis of accident analysis, operational analysis, or both. For each item, the procedures provide accident reduction factors and operational analysis procedures as appropriate.

Table 22: Project safety checking grid (Reference USA)

	Accident Analysis	**Operational Analysis**
CROSS-SECTION		
Roadway Widening	υ	
Shoulder Widening	υ	
Side Slope Flattening	υ	
Roadside Clearing	υ	
Paving Shoulder	υ	
HORIZONTAL ALIGNMENT		
Flattening Curve	υ	υ
Improving Superelevation	υ	υ
Improving Transitions	υ	
Widening Roadway on Curve	υ	
Roadway Realignment		υ
VERTICAL ALIGNMENT		
Flattening Grade		υ
Adding Climbing Lane		υ
Lengthening Vertical Curve		υ
INTERSECTION		
Adding Left Turn Lanes	υ	
Improving Sight Distance	υ	
Relocating Intersection		υ
OTHER		
Widening Bridge	υ	
Improving Interchange		υ
Resurfacing Pavement	υ	

V.4.2. Inconvenience

Measuring inconvenience on an existing road is mainly useful to anticipate short-term congestion phenomena with a view to better controlling them through operational measures. It is also relevant to long-term anticipatory action aimed at planning improvements such as increased numbers of lanes or grade-separated junctions.

The most natural method of predicting inconvenience would seem to be simulation. It requires the availability or development of *ad hoc* tools that represent the actual traffic system realistically and precisely, and are calibrated and validated on the basis of experimental data. Such tools exist (In France, Austria, Sweden, USA, etc.) but they are not necessarily representative of drivers' behaviour, infrastructure and vehicles in all countries.

V.5. The limits of quantitative measurements

Quantitative measurements are firmly established in road engineers' practices and they are recognized as providing designers and operators with information essential to their work, particularly as regards the technical quality of service or some aspects of in-use performance. However they have the drawback of not always giving a true picture of the states of mind of users and the way they perceive the quality of supply, nor of giving a good explanation of their behaviour patterns. For this reason, quality concerns relating to the way users' expectations are met have led road administration managers to consider using other quality indicators, which are the direct expression of users' opinions gathered from opinion polls. The following sections particularly address this qualitative dimension of their perception and behaviour.

VI. HOW THE USER PERCEIVES THE QUALITY OF SERVICE

VI.1. Factors influencing perception of the quality of service

The way the user perceives a road is influenced by several factors directly related to the road: its intrinsic or structural characteristics and maintenance condition; the use made of it by other users (for example, its congestion level) in conjunction with its operating level; its surroundings (the driver's vision is not limited merely to the strip of concrete or asphalt before him) and, in general, the place of perception. It has been shown, for instance, that drivers' attitudes to congestion and, in general, their estimation of journey times, are influenced by their interest in the environmental scene.

Other elements external to the road and its surroundings influence the user's perception. They are of a cultural nature and take into account values related to the age, experience, sex and socio-professional category of the user. Among these elements, and again using the example of perception of congestion, it is the quality of the prior information given to drivers on congestion, and more particularly its effect on their journey time, that enables them to put up with delays better. The vehicle must also be taken into account as, through its own comfort, size, weight or dynamic performance, it undeniably acts on the motorist's sensory system and therefore on his overall perception of the quality of service.

The motorist's perception is also dynamic and forms part of a project, which means that not only is it sustained by the vehicle's movement but it occurs within a travelling context. Is it a professional or personal trip? A short or long trip?

Qualitative surveys conducted in France on users' satisfaction with the national road network, reflect the following correlations:

- The more the trip is associated with professional activities, the less the user is satisfied
- Age influences overall satisfaction: the youngest and oldest are the most satisfied,
- Satisfaction decreases regularly with an increase in annual mileage,
- HGV drivers' satisfaction is slightly below the average,
- Drivers of motor caravans and cars drawing caravans show greater satisfaction,
- The less the motorist uses the road, the more satisfied he is.

VI.2. Methods and tools for measuring perception of the quality of service

These will be examined from the results of user surveys, such as those conducted in France and the United States. They show that whatever slight differences may be apparent between results, the user' perceives an overall service encompassing :

- the road as it is structurally, in its initial state and in its surroundings,

- ancillary services (phone, shops, restaurants, service stations),
- the maintenance service which maintains the level of performance of the initial road condition,
- the road operating service which ensures good traffic conditions.

VI.2.1. American experience

In 1996, the Steering Committee for the National Quality Initiative, consisting of representatives of the Federal Highway Administration, representatives of the States and the American Road Industry, published the findings of a telephone survey on satisfaction, conducted on a sample of 2,205 people. To begin the investigation process, seven major characteristics were identified, considered to be theoretically most important with regard to the way users were likely to perceive the quality of the national road network. These characteristics, each of which was composed of a series of indicators, are listed in Table 23 (p 129). This gives the level of overall satisfaction, through a combination of "satisfied" and "very satisfied" for each of the items.

In addition to the results in Table 23 (p 129), the fact-finders wanted to identify the items of greatest importance to users, so that improvements could be targeted more appropriately. As regards the respondents' satisfaction with the road transport system, the following priorities were highlighted for improvements to be made by those who build and maintain the network

- Priority 1 : Safety
- Priority 2 : Pavement condition
- Priority 3 : Free traffic flow
- Priority 4 : Maintenance response time
- Priority 5 : Condition of works
- Priority 6 : Trip comfort
- Priority 7 : Visual perception of the environment

Based on these results, listed in Table 23, a statistical method of linear regression was used to link these uncorrected results to levels of overall satisfaction and to take account of the fact that many replies were "no opinion". This gave rise to the following order of priorities for improvement:

- Pavement condition,
- Safety,
- Free traffic flow,
- Visual perception of the environment,
- Condition of works,
- Maintenance response time,
- Trip comfort.

Another aspect of the evaluation concerned the sources of income required to finance the improvements, with fuel tax winning 35% approbation, followed by vehicle registration fees (24%) and toll fees (15%).

Table 23: Quality-of-service indicators (Reference USA)

Characteristics	Satisfaction	Indicators	Satisfaction
Visual perception of the environment	62%	Design of rest areas Integration into the environment Landscape Visual appearance of noise barriers	65% 62% 61% 52%
Safety	60%	Lane widths Danger signs Instructions Surface marking Safety barriers Diversions Verge widths Lighting Rain on carriageway	68% 68% 67% 63% 60% 53% 52% 48% 46%
Condition of works	58%	Visual appearance Solidity Surface characteristics	61% 58% 55%
Trip comfort	56%	Direction signs Service signs Number of rest and service areas Variety of rest and service areas Number of emergency phones	75% 64% 54% 49% 32%
Pavement condition	50%	Noise Evenness Surface conditions Durability	50% 49% 49% 44%
Maintenance time frames	50%	Refuse collection Rest and service area cleaning Barrier repairs Snow clearing Pavement repairs	58% 58% 57% 56% 38%
Free traffic flow	48%	Accident call-out Toll payment times Congestion level Construction time	58% 47% 35% 29%

VI.2.2. French experience: the satisfaction barometer on national roads

The satisfaction barometer on national roads (excepting motorways, in the early years, was first implemented in France in 1994. Its aim was to find out the degree of satisfaction of users, gauge their expectations, determine poorly perceived amenities and equipment, assess the ability of the works to improve user satisfaction.

Table 24 gives the distribution of the themes and sub-themes of the survey.

Table 24: Themes and sub-themes of qualitative surveys (Reference France)

Themes	Road condition	Traffic conditions	Signs and information	Provision of services	Environmental development
SUB-THEMES	Quality of road surface Bendiness Number of lanes Maintenance and cleanness Road marking Improvements to verges	Trafficability Overtaking facilities Travelling speeds Visibility Roads through towns and villages Junction layouts Road condition in winter In-situ organization of roadworks	Directional information Road signs Tourist information Information on services Weather information Traffic information Information on roadworks ahead	Phone facilities Presence of shops and restaurants Emergency stopping facilities Rest areas Service stations	Trip comfort Site development Development of the entrance to towns Landscaping Maintenance of these amenities

Motorists are intercepted in the daytime outside the Paris region, on rural roads with dual carriageways, 3 lanes, 2 lanes, heterogeneous types (in total 20,000 users at 80 survey points). After they have stated the frequency, reason and length of their trip (short trips of less than 20 km are excluded from the scope of the survey), they are asked to express their degree of satisfaction on each of the themes. Finally, after statistical processing to obtain the confidence interval of the percentages of replies of the same type, each theme or sub-theme is given a rating from 1 to 10 (NR rating). It is also possible to indicate which sub-theme(s) have the most influence on the overall rating of a theme, by statistical analysis based on correlation and regression. For the safety theme, users are also asked a series of questions.

The most significant results likely to throw light on studies of quality of service appropriate to the available means, are as follows:

- The road condition and traffic conditions strongly influence the overall NR rating. The other themes have no effect.

- The assessment of road condition is strongly influenced by: surface quality, number of lanes, maintenance and cleanness, improvements to verges. The overall rating for 2-lane dual carriageway roads is much higher than that of other roads. All the sub-themes have a greater or lesser influence on the overall rating of the theme, except for road marking and bendiness which have no effect on 2-lane and 3-lane roads. Among the general theme-related observations, is the fact that in winter, some users are more inclined to use motorways (if they are relatively close) than national roads.

- The assessment of traffic conditions is strongly influenced by trafficability, overtaking facilities and visibility. Travelling speed only has a moderate influence on the rating. Among the general theme-related observations are the following. Traffic, percentage of heavy vehicles, and cross-sections have a strong influence on the perception of traffic conditions; the co-existence of light and heavy vehicles often leads to conflictual situations; road signs must be appropriately positioned; signs must be visible and their locations consistent with the road (geometry, critical points, junctions); information must be provided and must be reliable, the weather forecast must be credible.

- As regards safety, more than 80% of motorists do not consider national roads to be really dangerous. Satisfied users rather tend to underestimate road hazard, whereas the correlation between dissatisfaction and the impression of road hazard is closer. Road junctions are considered less dangerous than the road alignment. 82% of users underestimate hazard from side obstacles. Roads through villages are considered dangerous by 30% of motorists. General safety-related observations show that the number of lanes, surface quality and geometry are felt to be key safety elements. Motorcyclists consider that road markings are often inappropriate and slippery in rainy weather. They are also concerned by the safety barriers, some of which are considered extremely dangerous should they fall off their cycles.

- As regards the other themes, the main desire is for emergency phone facilities whereas there are few remarks on environmental development. It is merely noted that users respond well to clean, shady, flower-decorated parking areas.

The open-ended replies indicate the work considered most important by users. In the main, the most desired road features and services are, by order of priority:

- an increase in the number of lanes: directly related to traffic (ADT) and to the percentage of heavy vehicles using this type of road,
- pavement quality: consistency and quality of the surface,
- road marking : visible and reliable,
- verge maintenance: stabilization, mowing, pruning,
- Improvements to junctions and entrances to towns and villages: traffic lights, traffic calming devices, roundabouts and bypasses,
- road signs: clear visible signs, better advance signing,
- information: up-to-date and accurate,
- works to improve services: facilities for emergency stopping and phoning, refuelling, clean, friendly rest areas,
- environment: further site development. Fewer advertising signs and the eradication of uncontrolled dumping.

VI.3. Perception of the quality of service in relation to the different road types

The following results are taken from the barometer of satisfaction of French national roads and motorways. Despite some differences, bi-directional national roads (7 m), 3-lane bi-directional roads (10.50 m), heterogeneous roads (varying in cross-section) and 2-lane, dual unidirectional carriageways are perceived in comparison to motorways as flexible places where rules are not strict (road signs, speed limits, information, local improvements, geometry). What they lose in efficiency and safety they gain through opening up the vista towards the surrounding landscape.

VI.3.1. Bi-directional, two-lane roads (7 m wide)

The respondents are quite critical of 7-m wide national roads, which are not considered to be adequately functional and secure. Drivers of light vehicles have conflict relationships with heavy vehicle drivers, and this combined with the often restricting geometry of this type of road gives rise to extremely hazardous areas for overtaking. To overcome this problem, they give priority to increasing the number of lanes. Then come safety-related improvements: replanning road junctions, amending some bends, improving visibility and road markings. Work to improve rest areas and roadside planting is considered less important.

VI.3.2. Bi-directional, three-lane roads (10.5 m wide)

National roads with three designated lanes have quite a favourable reception. But overtaking is considered difficult when traffic is heavy because the sections provided to get back into lane are considered too short.

There are not enough phone booths and lorry lay-bys and the design of those that do exist does not permit parking.

VI.3.3. Heterogeneous roads (varying cross-sections of 7 m, 10.50 m, 2-lane dual carriageways)

Users criticize changes in cross-sectional widths and request that these sections are converted to 2-lane dual carriageways. Roads crossing towns and villages are particularly difficult where the carriageway narrows. Bypasses are considered the best solution to optimize the route. Improvements and maintenance of existing rest areas are often felt to be neglected.

VI.3.4. Unidirectional roads (2-lane dual carriageways)

Few complaints are made about these roads. Simply that the speed limits on some sections are considered inappropriate to the design of this type of road

VII. IMPACT OF THE QUALITY OF SERVICE ON THE BEHAVIOUR OF USERS

VII.1. Behaviour indicators and measurements

Before trying to gauge the impact of the quality of service on users' behaviour, it will undoubtedly be useful to characterize this behaviour. The replies to the question "What are the criteria used by your country to qualify the behaviour of users?" show that in fact few countries use specific criteria to characterize users' behaviour resulting from the way they perceive a certain quality of service. The most common criteria are the choice of transport mode, choice of route and the different forms of speed criteria.

VII.2. Choice of transport mode

Theoretically the factors that most influence the user in his choice of transport mode are journey time, comfort, safety and cost. Journey time is considered in terms of not only duration but also reliability. Comfort is mainly considered in terms of the continuity of the transport mode and consequently the absence of breaks in the journey. Naturally the user's choice is closely tied to the supply, and more particularly to the possibility of opting for an alternative solution. It also depends on the information available to him on this alternative solution. And we must also make a distinction between urban trips, where competition with road transport from the other transport modes will primarily concern commuting, and interurban trips where competition will tend to concern professional transport during the week and private trips at weekends and during holiday periods.

Two major trends deserve to be highlighted. The first is that most countries note a general increase in road travel, particularly trips in private cars. For example, between 1984 and 1996 in France, the number of car trips per person per year to destinations more than 100 km from home, increased from 4.1 to 7.2. Thus the private car, for all user categories combined, takes precedence among the various modes of transport. It is considered as the most practical means of getting from one point to another without breaking a journey. The second trend: those same French users, in their growing concern for urban traffic problems and their desire for improvements in long-distance traffic, have become increasingly reticent about the creation of new roads over the past few years – and they are not alone in this. In urban areas, "car-only" advocates have become a minority group (13%) and most people are calling for more incentives to use other transport modes. For an increasing number of users, such incentives cannot be dissociated from the development of public transport and the creation of park-and-ride facilities at the outskirts of towns.

But these incentives could also consist in restricting the use of private vehicles in towns through taxation systems or urban tolls such as those tested out in Singapore, Bergen, Oslo and Cambridge. In rural areas, a trend reversal has also been noted among French users in recent years. Development of the motorway network, which headed the list of preferences for controlling growth in road traffic, is less and less popular, particularly among young people. Users now prefer difficulties to be solved by improving the operation of the existing network and providing incentives to use other transport modes.

These trends are obviously closely correlated with the sensitivity of users to environmental problems. Although considerations such as comfort, safety, free traffic flow and transport costs are taken into consideration when choosing a transport mode, it is just as true that users are increasingly sensitive, particularly in urban areas, to the environmental impact of the transport modes.

In the end, it seems as though, when choosing a transport mode, positive feedback on the quality of service of a road is not the main criterion, because competition from the other transport modes cannot hold up to the quasi-emotional bond between motorists and their cars. The reverse is true for the other modes which continually have to make commercial demonstrations of their advantages and their quality of service to attract customers. However, the negative components of the quality of road service, measured in hours of traffic jams, the impression of road hazard, pollution, noise, etc. may partially turn users towards other transport modes. Such unpleasant sensations can be exacerbated still further by having to pay taxes and tolls. But these may be considered fair and justifiable insofar as they aim to better regulate the transport system and consequently benefit all users.

VII.3. Choice of route

The choice of route is a good indicator of people's interest in the quality of service on one road in relation to another. Moreover to improve the relevance of traffic forecast studies, it is useful to find out users' motivations in their choice of route. A recent study, combining a quantitative and a qualitative approach, conducted by the *Association des Sociétés Françaises d’Autoroutes* (ASFA, Association of French motorway companies), provides interesting findings on choice criteria. The desire for safety (or the impression of safety) is paramount and is mentioned by 75% of motorists. It is accompanied by a strong sensitivity to the journey time (54%). Comfort is ranked as the third concern (24%). The cost of the trip is a marginal consideration (12%). More precisely, the main concern of drivers "in a hurry", who account for 40% of the population studied by the association, and who travel some 29,000 professional km and 17,000 private km per year, is to arrive as quickly as possible with the minimum number of contingencies. They are therefore very sensitive to the reliability of journey times. This category of motorists consists mainly of people who use the road for professional reasons. Conversely, leisurely drivers who make up 18% of the population under study and are mostly people over the age of 65 making private trips, look for easy, less tiring and more pleasurable routes. They are not very sensitive to cost and speed.

Between these two categories, the "reasonable" motorists (28% of the population under study) are very aware of accident risks, fatigue and contingencies, and the "thrifty" motorists (14% of the population) seek out the shortest-distance route even if it means foregoing pleasure, comfort and facility.

The trend constantly highlighted by surveys on users, whether in their choice of route or transport mode, is their desire for the trip to go as planned, with fewer contingencies. This explains the considerable weight of experience and habit in the motivations of choices, which induce them to keep to familiar ground. Two conclusions can be drawn from this, which will either strengthen or change their habits. They must be clearly informed of the quality of service they can expect from the road they intend to take – and they must not be disappointed. As it is out of the question to distribute the road specifications at the entry to a road, in practice, this requires road objects that are perfectly self-explaining in terms of quality of service. Users may be quite willing to adapt to an "intermediate" quality providing they have been informed beforehand and the expected services are actually provided. It is up to road designers and operators to identify the nature of these expectations through qualitative surveys.

This is not without effect on the concept of intermediate roads, as it means that the more road owners and operators succeed in clarifying the road's intrinsic characteristics and overall performance (as they do for motorways), the greater the place these roads will occupy in the distinction made by users between the different road types.

VII.4. Speed

As regards perception of the quality of service and the impact of this perception on the behaviour of users, it is naturally actual travelling speeds which must be considered here. The speed travelled all along the road is quite indicative of the service level, all other things being equal. This is because a higher speed will generate greater accident risk and severity, all other things being equal. Surveys on this subject have shown that when people have the possibility to drive fast, this is usually associated in their minds with greater road surface comfort and with divided carriageways which reduce the risk of head-on collisions and facilitate overtaking. It is also associated with grade-separated junctions and by-passes. To a lesser extent, it is associated with efficient road signs which make anticipatory action easier, particularly when pulling back into lane or exiting.

This list of these relevant criteria is bound to link high speeds with high service-level roads, particularly motorways and divided carriageways. But although there is a clear connection between road characteristics and travelling speeds, this does not mean that speedalone is people's priority concern.

Moreover, most countries have introduced speed limits, including on motorways, which even though they are regularly exceeded, nonetheless have a restricting effect on drivers and contribute towards safety. What interests motorists most is not so much being able to drive very fast, as what this means in terms of safety and comfort with regard to the foregoing road characteristics. Above all, the guarantee of a regular speed will enable them to plan a fairly reliable journey time. Habitual motorway users realize that a regular speed will reduce their journey time more than high speeds alternating with sharp decelerations or even stoppages. They also know that a regular speed means less stress, less consumption and less pollution.

Conversely it is tempting to imagine that perception of the road which gives users a feeling of discomfort or even stress and danger, should encourage them to reduce their speed, for it is a fact that travelling speeds are not always consistent with the level of safety offered by the road. Indeed, in rural areas it is much easier to obtain the reverse effect by introducing more or less artificial constraints. You only have to observe what happens when passing roadworks, where it is sometimes a real problem to make motorists slow down. In fact, it is extremely difficult to devise a strategy to reduce travelling speeds based on improved geometrical lane design. For example, the geometrical constraint imposed by the horizontal alignment on travelling speeds only becomes a determining factor below a 250-m radius.

VII.5. Quality-of-service factors perceived by the user which influence his behaviour

Table 25 depicts the main areas of influence.

Table 25: Quality-of-service factors perceived by the user which influence his behaviour

	Modal choice	Route choice	Speed
Road type	0	+	+
Alignment	0	+	+
Cross-section	0	+	+
Pavement	0	0	+
Services	+	+	+
Environment	+	+	+
Traffic	+	+	+

It has already been shown that modal choice is not greatly influenced by road characteristics. On the other hand, the sensitivity of users, particularly young people, to pollution problems, and the sensitivity of older people, particularly women, to risks of aggression, explain the relevance of the modal choice to services and the environment. Pavement characteristics have little effect on the choice of a route, however users a very aware of pavement condition (VI.2.1 and VI.2.2). And in some countries where the user may have to choose between a surfaced route and an alternative unsurfaced route, pavement characteristics have a real impact. The effect of the road type on the choice of a route is particularly significant when deciding between an ordinary road and a motorway, particularly a toll motorway.

The services offered and the environment also influence the choice of route and depend on the type of trip (VII.3). Speed is mainly influenced by the cross-section, and the separation of the carriageways probably has a greater effect than the width of the lanes. However, other factors liable to influence speed must not be overlooked, such as pavement surface quality, the type of environment (II.1) and, to a lesser extent, the alignment which, to have an inhibiting effect must include radii with particularly marked constraints. As regards services and their effect on speed, it is clear that operating services have an influence on travelling speeds. Traffic affects the choice of mode, the choice of route and the speed (III.2.10 c and IV.2.2. b). But for the first two choices, the user needs to be warned early enough and the speed may be unresponsive to wide traffic flow ranges.

VIII. COMPARING SUPPLY WITH SERVICE DEMAND: RANKING THE LEVELS OF SERVICE

VIII.1. Examples of use of the service level concept

VIII.1.1. American experience

The best-known reference to the service level concept is that of the Highway Capacity Manuel, which characterizes the different acceptable peak-hour congestion levels by letters from A to F (III.2.3 b).

Table 26: Characterization of service levels (Reference USA)

Levels of service	Description
A	Free flow, low traffic and high speeds
B	Reasonably free flow but speed begins to be hampered by the traffic
C	Steady flow but most drivers are hampered in the freedom of choice of their own speed
D	Nearing unsteady flow. Drivers have little choice of their own speed
E	Unsteady flow, sometimes short stops
F	Unacceptable congestion

These service levels are used for planning and designing roads. They are pre-defined, to allow for such considerations as the road function, users' requirements, and environmental characteristics. The influence of these parameters is obviously weighted by the funds available to meet users' requirements. But the initial choice of the service level is extremely important as it will naturally condition the dimensions given to the road and particularly its consistency with expectations. For example, the AASHTO Green Book gives the following indications for selecting the service level.

Table 27: Selection of service levels (Reference USA)

	Type of environment et appropriate service level			
Road type	Rural flat	Rural rolling	Rural mountainous	Urban et suburban
Freeway	B	B	C	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

This example of the application of the service level concept to planning and design is interesting because it shows how a certain form of initial ranking in the performance levels of the road undergoing improvement, can guide designers in their technical choices. Another interesting aspect of this approach is the fact that it places the user at the centre of the evaluation system. For in fact, the aim is not to base the road's geometrical characteristics on a predetermined service level value, but to make the road operations consistent with users' expectations.

VIII.1.2. French experience

In another field, that of road operations, the service level concept can also be applied. This is because the continual growth of traffic in most countries is leading to increasingly frequent disruption. To attenuate its effects, France decided to implement an operational master plan for the purpose of: improving the efficiency of road serviceability operations; ensuring efficient management of traffic flows wherever necessary; providing travelling assistance by organizing road information. The final objective was to make organizational arrangements consistent with the means available for the operating levels. These operating levels were elaborated from basic tasks and the corresponding service level indicators for each of the following action areas: road serviceability, traffic management and travelling assistance. They were then ranked into four possible levels in interurban areas. Table 28, for example, taken from the French document setting out the road operation master plan, gives the levels for the "serviceability" area indicator. The same document gives the levels for the "traffic management" and "travelling assistance" indicators.

Table 28: Levels of service of road serviceability (Reference France)

<table>
<tr><th></th><th>4</th><th>3B</th><th>3A</th><th>2</th></tr>
<tr><td rowspan="2">General network supervision</td><td rowspan="2">Non-systematic</td><td colspan="3">Systematic</td></tr>
<tr><td>When on duty and where required off duty</td><td>Organized with standby in off-duty hours</td><td>Permanent</td></tr>
<tr><td rowspan="2">Warning time defined with partners</td><td colspan="2">Random</td><td></td><td></td></tr>
<tr><td>If possible < 60 mn during hours of duty</td><td>If possible < 45 mn during hours of duty</td><td>In principle< 30 mn</td><td>< 20 mn</td></tr>
<tr><td rowspan="3">Emergency call-out</td><td colspan="4">Organized</td></tr>
<tr><td colspan="2">During hours of duty with < 45 mn response time</td><td colspan="2">Round the clock with a response time of:</td></tr>
<tr><td>As possible during off-duty hours</td><td>With variable response time on standby duty</td><td>in principle < 30 mn daytime < 45 mn night-time</td><td>< 20 mn day and night</td></tr>
<tr><td>Winter service</td><td>L2</td><td>L1 or L2</td><td colspan="2">L1</td></tr>
<tr><td>Worksites</td><td>Planned</td><td colspan="3">Planned or organized according to traffic</td></tr>
<tr><td>Equipment maintenance</td><td>Preventive and curative</td><td colspan="3">Preventive and corrective subject to a response time</td></tr>
<tr><td>Convoys and special events</td><td colspan="3">Taken into account</td><td>Taken into account with organization and heavy constraints imposed where possible</td></tr>
</table>

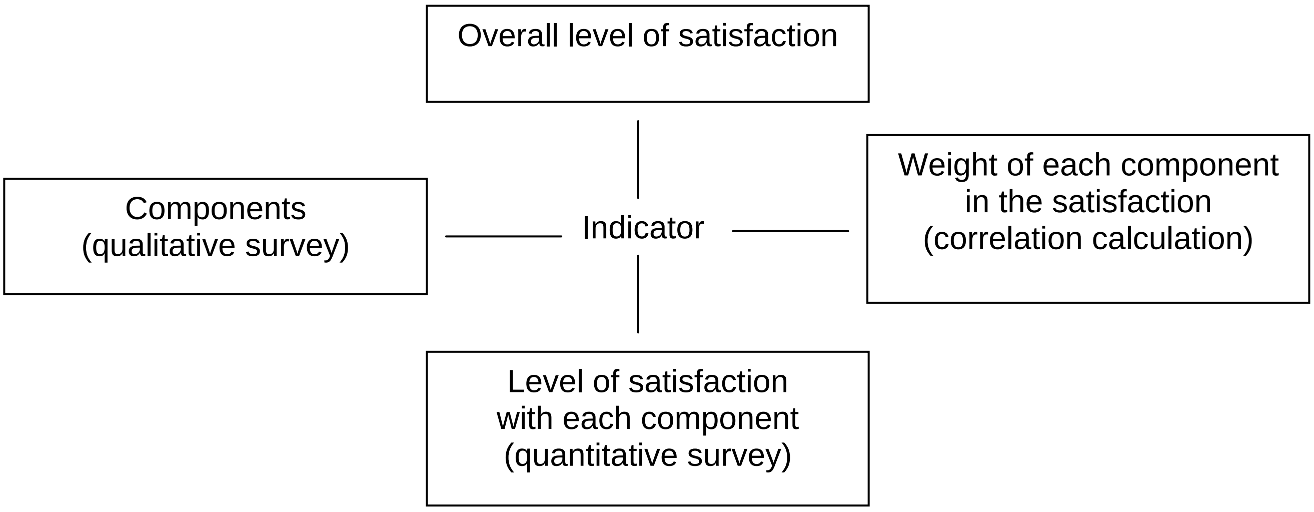
Road operation surveys have shown that users primarily expect the road service to lessen uncertainty – the road service must measure up to their requirements in terms of regularity, safety, driving comfort and information. In other words, users are perfectly capable of understanding that the road cannot offer them everything. But a service level once announced must be provided. This also means that when a problem arises, motorists expect the operating services to attenuate its consequences, with a swift return to a normal situation.

In 1989, the Paris-Rhine-Rhone Motorway Company (S.A.P.R.R.) began to study a method for evaluating and monitoring the service level on its motorway network. This method, which was implemented in 1991 is in three parts: a qualitative analysis followed by a quantitative analysis on customers and finally the reconstruction of an analogue model.

The basic qualitative survey enabled customers to express their satisfactions, criticisms and expectations of the motorway and their trip. As a rule, it was made open-endedly while travelling, on representatives of major customer segments (HGVs, light leisure vehicles, light utility vehicles) and on a varying trip path sample.

The results were summarized in the form of a structured list with 38 service level components. This list reveals a paradox. The motorway user bases his choice on objectives of rapidity and safety, considered essential, and yet he bases his judgement of the service on a large number of characteristics considered of secondary importance, related more to quality and comfort.

Based on the list of 38 items, a quantitative survey was then made, in which a sample of customers was asked to give the service corresponding to the items, taken both together and individually, a rating from 0 to 20, or to rate it over a scale with four levels of satisfaction.



The survey was processed to obtain directly:

- the overall level of satisfaction,
- the rating of each of the items,

and by calculation, the weighting of each item, using a polynomial function of the type:

$$I = K + \sum_{i=1}^{n} c_i \cdot N_i$$

where I is the overall rating

K is a constant
n is the number of components
c_i is the weighting coefficient }
N_i is the rating } of the component i

This method, proposed by a specialist firm, had not yet been applied to the motorway sector but to different sectors whose experience was put to good use.

Because of the difficulties, and more particularly, the cost of frequently repeating a large-scale survey at that time, the firm chose only to retain the basic framework of the model to monitor the service level trend, i.e. the weighting coefficients and, in the ratings, to replace the survey findings by indicators obtained from internal administrative data.

For this purpose, a considerable amount of work went into finding these indicators in the available statistical system, and ensuring that the results were well correlated with the test survey. For example, road comfort was represented by a medium-frequency evenness indicator; safety by integrating an overall result indicator (accident rate) and more elementary indicators (complaints about litter on the carriageway, a lack of delineators, worksite accidents and complaints); ancillary area availability by exceeded thresholds determined during night patrols.

The method resulting from this work was tested in two of the firm's regional operation branches (9 districts) and revised before it was generalized. Since then, the calculation has been made on a quarterly basis in the districts, thus forming a valuable historical data base, the analysis of which obviously raises as many challenging questions of method as it furnishes solutions.

VIII.1.3. Italian experience

References for defining a service level encompassing several road quality dimensions such as safety, free traffic flow, accessibility, comfort, service to users, the environment, are virtually non-existent. This gives particular relevance to the S.A.P.R.R. model outlined in the previous section and to Italian experience in determining a single overall quality-of-service indicator for some fifteen motorway sections of the Autostrade company. Along similar lines, the method proposed by the Italian members of Committee 4 (Roads, Transport and Regional Development) opens extremely ambitious prospects. This method aims to identify, standardize and combine the quality-of-service factors of a road network, in an overall service level.

For the example of the Autostrade company, the overall indicator integrates secondary, mobility-related indices (accident rate, accessibility indices, free flow index) and quality evaluation indicators for the service areas. The quality-of-service measurement uses an analysis model called CASTORE (Customer's quAlity monitoring System on the Italian moTORway nEtwork). This model gives a computerized image of traffic flow conditions and highlights major malfunctioning. It also proposes solutions for infrastructure improvement characteristics and for road operations. Based on an "Analysis of the degree of customer satisfaction with service areas of the Autostrade company", an efficient quality measurement system has been introduced on 207 service areas, with a further objective of providing appropriate solutions for recorded deficiencies. The proposed method is consistent with the following specifications:

- weighting the key factors and the main constituent elements according to their specific importance,
- enabling qualitative and quantitative synthetic evaluations of quality,
- guaranteeing service level comparisons recorded on the different road sections,
- identifying the service components that require priority work to improve quality,
- defining a standard of service and setting objectives for improvement,
- making the interpretation of quality easier for all the Management of the motorway sections, taking account of the devolution of responsibilities,
- channelling corrective measures towards infrastructure work or road operations,
- ensuring consistency with the evaluation logic of variations in quality "ΔQ" provided in the new pricing system
- laying the basis for better structuring of monitoring systems.

The secondary indices are as follows:

- Ti : accident rate,
- Ia1: accessibility index, expression of the percentage of vehicles in queues at toll gates, with reference to the total number of vehicles in transit,
- Ia2: accessibility index, expression of the mean unitary waiting time at toll gates,

- If1 : free flow index, expression of the percentage of vehicles in queues or slow-moving traffic on the motorway route, in relation to the number of vehicles in transit,

- If2: free flow index, expression of the mean unitary waiting time on the motorway route,
- Isr: level-of-quality index of service areas.

Each index is measured against a scale of values from 1 to 4, depending on the actual measurement result, and it is associated with a weighting factor. For example, the accident rate is valued according to table 29 and it is given the highest weighting coefficient, which is 0.4.

Table 29: Valuing accident rates (Reference Italy)

Value	Accident rate
4	10 > Ti
3	10 < Ti < 14
2	14 < Ti < 18
1	18 < Ti

Table 30: Levels of service (Reference Italy)

Section Management	IQG	Service level
DT1	2.0	C
DT2	2.3	C
DT3	2.3	C
DT4	1.8	C
DT5	2.3	C
DT6	3.4	B
DT7	2.2	C
DT8	3.6	A
DT9	2.9	B
Network	2.1	C

The formula of the overall service indicator is thus as follows:

$$\mathbf{IQG} = 0{,}4.\ \nu Ti + 0{,}1.\nu Ia1 + 0{,}1.\nu Ia2 + 0{,}15.\nu If1 + 0{,}15\nu If2 + 0{,}10.\nu Isr$$

In this formula, νTi, νIa1, νIa2, νIf1, νIf2, νIsr represent the values between 1 and 4 of the different indices. The values calculated for the overall indicator are then given according to a classification scale ranging from A for the best to D for the worst.

For instance, table 30 gives the results obtained by the different motorway section Management.

Another illustration of the quantification of an overall quality-of-service indicator is the proposal by the Italian members of Committee C4 (*), formulated in the work of this committee.

According to them, the quality of service of a road section can be expressed in a single parameter: LSA (Livello di Servizio Allargato) or overall service level. This level may vary between a theoretical maximum value, corresponding to the presence of all road services, and a minimum permissible value that will guarantee the basic road functions. Between these two extremes, it is possible to introduce intermediate values that enable the quality of service provided by the infrastructure to be synthetically classified. Table 31 (p 161) gives the service level intervals.

Table 31: Service level intervals (Reference Italy)

Level A	0.85 < LSA < 1
Level B	0.67 < LSA < 0.85
Level C	0.50 < LSA < 0.67
Level D	0.30 < LSA < 0.50
Level E	0.20 < LSA < 0.30
Level F	0.13 < LSA < 0.20
Level G	LSA < 0.13

The Italian Committee gives the following description of these service levels and the method for obtaining the overall service level by combining various indicators.

A. The upper limit is that of motorways with good lighting. The lower limit is obtained on a road with all the geometrical and safety standards provided for motorways, except for certain services.

B. The lower limit corresponds to roads with divided carriageways, having a level of safety that is very high but lower than that on roads corresponding to the previous interval. Comfort related to the roadway components is the same as on roads corresponding to the higher level. But there may be a few overall comfort deficiencies.

C. This is the interval for single-carriageway main roads. But it may possibly include divided-carriageway roads on which significant comfort components have been neglected.

D. The lower limit corresponds to roads characterized by a virtual lack of service and with deficiencies in their intrinsic safety.

E. The lower limit corresponds to roads with relatively low functionality and a constrained alignment.

F. The lower limit corresponds to roads with poor functionality, on which practically none of the dimensions and characteristics meet the requirements.

G. All secondary roads with a 40 kph speed limit belong in this interval.

The entire quantification procedure of the overall service level is based on a simple basic principle: quality of service in terms of road serviceability is the sum of the judgements that can be associated with a specific number of basic qualities which each contribute, through their inherent value, to the final evaluation. The basic qualities for which the incidence is greater than the approximation error are the service "indicators" for road serviceability.

A judgement method is associated with each indicator and enables a numerical value to be allocated to the road section in question, for each of the basic qualities. It is necessary to record the indicators quickly and cheaply and they must be consistent with an objective evaluation of road features. As there are many indicators, it is more practical to group them together according to criteria of homogeneity such as comfort, trip time, services, environment or traffic characteristics. The safety indicators can in turn be classified with reference to geometrical, structural and functional characteristics, or with reference to external influences.

The overall service level takes account of the points of view, not only of the project owner but also of the users and the external environment. Each indicator (with reference to each point of view) has a specific weight within the indicators of a group. And each group has its own weight in relation to the other groups. The attribution of weighting has been made on the basis of common sense and consistency. The final attribution will only be obtained after adjusting the method by applying it several times and validation by the relevant experts. These indicators must also be adapted to the different road typologies because it is obvious, for example, that emergency call equipment will not have the same importance on a motorway as on a secondary road. The weight of the indicators may also vary according to the road section: link section, viaduct or tunnel.

It is also helpful to divide the road into homogeneous sections from the point of view of their geometrical, environmental, traffic or other characteristics, in order to associate with each section the corresponding value judgements. This analysis will be made easier by providing appropriate data books and possibly by computerized data bases built up by the road managers. To make the method more operational, an algorithm has been developed in a computing programme available on an Internet site.

There are many applications for the method.

In new infrastructure projects, the LSA can be calculated for the different solutions in order to clarify choices. It is possible to inform decision-makers and public opinion by drawing up focus papers that identify the LSA parameters, either individually or grouped under themes, which characterize the road sections according to the different points of view. These parameters would highlight the elements worthy of interest and certain difficulties, which would enable a clear analysis to be made of all technical or non-technical indicators for each alternative.

In maintenance and operating phases, the priorities for choosing the sections on which to apply maintenance or traffic operation measures can be guided by comparing the LSA values. It is also possible to determine the minimum LSA values to be obtained over given periods, in order to evaluate the required resources precisely and to develop economic and financial programming based on objective technical data. The advocates of this method emphasize that these objectives may form part of an overall, coordinated maintenance and operating strategy, because in a particular sector it will always be possible to associate the same minimum values with a specific group of indicators.

Another application proposed by the advocates of this method, which is closer to the quality approach, is that of the use of LSA by the road administration to evaluate the performance of the operating centres. They could also check the implementation of policies and strategies recommended by the higher organization levels, by comparing specific indicators.

The Italian Committee members point out that to be efficient, development of the method should aim to better take into account the cost impact. In the present LSA concept, and in the proposed algorithm, the costs are only considered through the weight to be given to the project owners' point of view

VIII.2. Clarity in the ranking of service levels for users

Generally speaking, the service levels referred to by designers, maintenance practitioners and operators are rarely explained to users. For example, a road's service level is seldom displayed at its entry. However, motorists are indirectly informed through a few well-known signals. Road maps which clearly distinguish the road types, particularly motorways from roads with bi-directional traffic, are good service level indicators. And on closer examination, motorists can also identify toll motorways, which they associate with a high service level, as shown by surveys conducted in France. Although the classification of road types (see III.2.1) is not self-explaining in all its dimensions to users (in fact they only distinguish between motorways and ordinary roads), it is nonetheless an initial service level indicator, which operators do not need to explain further. Other implicit signals of the quality of service for users are: location references such as the landform, urban character or rural character of the environment. Lastly, users do not expect to encounter the same treatment on a link section as on a section on a bridge or in a tunnel.

Besides these signals, there is nothing that can give motorists indications on the structural service levels of the road network early enough to enable them to make decisions. That is why it is necessary for road designers to create roads whose identity is sufficiently perceptible to enable them to encounter what they expect. The explanation of service levels is a rational step for owners, maintenance practitioners and operators. It is more important than the offer of service and give users markers that enable them to rationalize their choices. In this respect, displaying a level of structural service has limits in terms of temporal validity. It is therefore necessary to use other methods of displaying a service level in real time, based on information systems ranging between the most conventional, such as dynamic equipment or radio, to the most sophisticated, such as onboard ATS systems.

VIII.3. Evaluating the cost of quality of service

The quality of service that a road can offer, is the sum and weighting of the various services rendered to users by this infrastructure. The definition of a simple system, clearly derived from various components of these services and from their importance, should enable the road to be "rated" over a quality scale previously defined for the selected criteria taken as a whole or separately, according to the examples given in VIII.1.3. For each service provided and its weighting in the quality scale, there could be an associated evaluation of the cost of this service or the differential (in %) it represents in relation to a road without the service in question. These evaluations should enable designers to measure the cost of the quality of service of a road link.

An important point must be emphasized. The quality of service may have a cost, but not providing the service, or providing it inadequately also has a cost. This cost affects the user, in terms of safety or time savings, for example. But it also affects the owner insofar as the conservation of his assets may be jeopardized by poor maintenance. The road operator can also be concerned, in a toll motorway context, as the user-customers may simply stay away, which will affect the income money. Just as non-quality has a cost, excessive quality also has a cost. Indeed it is not uncommon for road engineers to be overconscientious rather than leaving work undone, which is naturally bad for project costs.

The problem of excessive quality can be illustrated by the significant example of salient (hill-top) angle radii on longitudinal sections. A recently observed trend in France for motorway projects has been to adopt extremely gentle longitudinal sections, often longer than 15,000 m, whereas the minimum length specified in the French standard, for a design speed of 120 kph, is 10,000 m. The aim here is not to discuss whether such an option is justified. Table 10 in section III.2.8 (p 57) clearly shows that France is the country that has adopted the lowest minimum value (half that of Germany or Switzerland). And if actual travelling speeds (*V 85*) are taken into account, levelled down to the regulatory speed of 130 kph, it is effectively a radius of 15,000 m which ensures the 275 m stopping distance from a 0.35 m high obstacle, corresponding to 130 kph. The idea here is simply to illustrate the extra cost of earthworks when, to cross a hill, the radius chosen is 15,000 m rather than 10,000 m, and to compare this extra cost with the gain to be achieved in terms of quality of service. This calculation was made for the revision of French motorway standards now in progress. The extra costs of earthworks, for low or medium trafficked motorways, in rolling country, and for different base lengths of the hill to be crossed, are given in table 32.

Table 32: Extra cost of earthworks when the radius passes from 1,000 to 15,000 m (Reference France)

	Extra cost of earthworks compared to a 10,000 m radius in millions of 1995 francs				
Base length	600 m	800 m	1,200 m	1,600 m	2,000 m
Radius 15,000 m	0.38	0.90	3.05	7.25	14.18

Based on these results – which can also be read the other way round, in terms of savings when a radius 10,000 m rather than 15,000 m, for example – it was interesting to compare savings on earthworks with the extra social cost of accidents on an upward gradient and a downward gradient, to which an extra cost of dynamic signing must be added. A sharper longitudinal section causes reduced visibility at the top of a hill, and owing to the increase in the slope, results in an extra risk of accidents on the downward gradient. Furthermore, the use of variable message signs may partly offset the extra costs of safety, particularly those related to the loss of visibility at the tops of hills. Table 33 (p 169) shows the results obtained (economic evaluation discounted over 30 years in millions of 1995 francs) for a radius of 10,000 m rather than 15,000 m. They are always positive.

Table 33: Economic evaluation of savings on earthworks (Reference France)

Downgrade lengths	**300 m**	**400 m**	**600 m**	**800 m**	**1000 m**
Variation in slope in %	1∏1.5	1.3∏2	2∏3	2.7∏ 4	3.3∏ 5
Extra cost on upgrade	0	0	0	0	0
Extra cost on downgrade	0	0	0.8	2.10	5.2
Extra cost for signing	0	0	0.5	0 .5	0.5
Total extra cost	0	0	F 1.3 m	F 2.6 m	F 5.8 m
Savings on earthworks	F 0.4 m	F 0.9 m	F 3.0 m	F 7.3 m	F 14.2 m
Economic evaluation	F + 0.4 m	F +0.9 m	F +1.7 m	F + 4 .7 m	F +8.4 m

Thus, from a strictly economic point of view, the savings on earthworks are always greater than the extra cost of safety, by reducing a radius from 15,000 m to 10,000 m. It can thus be inferred, solely against the safety criterion, that excessively gentle longitudinal section radii give rise to excessive quality. But this would overlook an important dimension directly related to the reduction of the longitudinal section, which is the increase in slope. This places heavy vehicles at a great disadvantage in terms of both lost time on upward and downward gradients and fuel consumption. And if the users' evaluation is integrated, taking into account lost time and additional consumption, the overall result of adopting a sharper longitudinal section becomes negative.

This example shows how difficult, but also how useful it is, in the evaluation of quality-of-service cost, to link a particular change pattern in intrinsic road characteristics, or essential technical components (c.f. table 3, p 27), or a particular associated service component, to measurable criteria of overall performance.

IX. SUMMARY OF THE MAIN ACTIONS TO IMPROVE THE QUALITY OF SERVICE

IX.1. Areas of action on service supply and demand

The following three tables summarize the main points on which owners, road designers and operators can concentrate to enable supply to correspond more closely to service demand. Obviously not all the aspects of this long list of actions have been examined in detail in this paper. And attempting to cover the quality of service of a road in a single document, would be taking the risk of skimming over a particularly vast subject concerning many sectors and many beneficiaries. This paper has therefore focused on certain aspects of quality, for which it has examined the implications in the different phases of the road's life cycle, from the idea of the project to the operation of the road in service, clearly differentiating the responsibilities of the key players. The breakdown of actions on supply and demand covers three major areas: general policy, project development (distinguishing between the definition of specifications by the owner and the design performed by the engineer), and the service life of the road (during which the maintenance and operation managers become involved). This breakdown is given in tables 34, 35 and 36.

Table 34: Quality-of-service optimization in general policy

Action areas	Action on supply	Action on demand or knowledge of demand
General policy	❑ General road planning policy ❑ Road budgets ❑ Functional classification of the network ❑ Technical policy - road typology - road standards - flexibility in relation to standards ❑ Investment policy/existing road rehabilitation/maintenance ❑ Linkage with new partners (new technologies)	❑ Transport policy, intermodality ❑ Communication and information policy ❑ User training/education ❑ Opinion polls, user forums ❑ Project development procedures integrating users ❑ Traffic regulations ❑ Road taxing/pricing ❑ Setting up observatories (safety, environment, economy) ❑ Defining service level indicators

Table 35: Quality-of-service optimization during project development

<table>
<tr><th>Action areas</th><th>Action on supply</th><th>Action on demand or knowledge of demand</th></tr>
<tr><td rowspan="4">Project development</td><td colspan="2">DEFINITION OF SPECIFICATIONS</td></tr>
<tr><td>❑ Programming / financing
❑ Quality approach
- clarification of owner's and engineer's roles
- quality of the order and target costs
❑ Functional analysis
❑ Knowledge of functional costs
❑ Adaptation to local constraints
❑ Adaptation of service level to strict necessity
❑ Risk analysis
❑ Reduction of uncertainties
❑ Choice of design speed
❑ Major planning options
- layout / vertical alignment
- horizontal alignment, separated or unseparated carriageways
- interchange system
- grade-separated or at-grade junctions
❑ Homogeneity of routes</td><td>❑ New skills to be developed
- prospective analysis
- communication
❑ User consultation
❑ Transparency
❑ Taking operation and maintenance into account in the functional road specifications</td></tr>
<tr><td colspan="2">PROJECT DESIGN</td></tr>
<tr><td>❑ Engineer's organization
❑ Freedom given to designer based on programme development / contractor's alternative solutions
❑ Value analysis
❑ Excessive quality control
❑ Derogations from standards
❑ Use of intermediate road types
❑ Main characteristics of the road
❑ Ancillary services
❑ Action on capacity adjustment factors
❑ Environmental protection measures
❑ Project safety control
❑ Public contracts / free competition</td><td>❑ Explaining choice of solution
❑ Compliance with owner's commitments
❑ Handing over of works accompanied by maintenance documents
❑ Appraisal after functioning of works
❑ Taking operation and maintenance into account in the design</td></tr>
</table>

Table 36: Optimization of the quality of service during the road's service life

Action areas	Action on supply	Action on demand or knowledge of demand
	ROAD MAINTENANCE and/or OPERATING	
During the road's service life	❑ Programming / financing of maintenance and operating ❑ Ranking of service levels ❑ Winter operations ❑ Response times ❑ Incident management ❑ Quality procedures in the maintenance and operating services ❑ Knowledge of maintenance and operating costs ❑ Asset management ❑ Intelligent network management ❑ Technical innovation ❑ Correspondence between maintenance and operating objectives and quality-of-service objectives ❑ Adaptation of service level to the space and use concerned ❑ Preventive / curative policy ❑ Maintenance and operating strategies ❑ Route-based maintenance and operating charters ❑ Maintenance and operating charters for service areas ❑ Pavement skid-resistance ❑ Legibility of the road and signs	❑ Systems of information to users ❑ Traffic management ❑ Reserved lanes ❑ Travelling assistance: driver information and guidance ❑ Development of information in real time: prediction of trip time, congestion, roadworks, accidents ❑ Access control ❑ Variable message signs ❑ On-board systems ❑ Toll-based traffic control ❑ Electronic fee collection ❑ Police controls ❑ Quality audits of operating and maintenance systems ❑ Information systems on network condition ❑ Performance trend prediction tools ❑ Opinion polls ❑ Worksite communication ❑ Temporary road signs ❑ Alternative routes

IX.2. Example of action on supply and demand within the scope of traffic management

The following example reproduces annex 6: "Traffic management" of the Instruction on "Methods of economic evaluation of road investments on rural roads", published in 1998 by the French Directorate of Roads. The aim of this annex is to provide elements for an initial analysis enabling the important issues to be determined from the simplified analysis grids presented below. A more in-depth study should be undertaken when this initial analysis shows the traffic management benefit of delaying a project, particularly in a reference situation, or as an operation forming part of the project.

Traffic management measures aim to improve traffic conditions as regards both safety and free traffic flow. For the traffic flow, a number of traffic management tools make it possible to influence the supply or the demand for capacity (by distributing it in space or time), or on both at the same time.

To achieve "gains" in terms of capacity and demand, various tools are available which, when combined, form a system meeting precise objectives. The efficiency of this system may vary greatly according to the network configuration, type of traffic, time of day or type of disruptive event. The following traffic configurations will subsequently be differentiated:

1 Seasonal holiday traffic
2 Weekend outgoing and incoming traffic
3 Morning and evening peaks
4 Heavy traffic, relatively constant throughout the year

together with different network configurations.

The following table itemizes the traffic management objectives and the corresponding tools in relation to the different traffic and network configurations.

Table 37: Traffic management objectives and the corresponding tools (Reference France)

Objectives	Tools	Traffic configuration
Optimize capacity supply	- speed control - access control - traffic light plans - local resident access regulations and/or facilities - parking bans	3 3 1, 2, 3 and 4 3 and 4 1, 2,3 and 4
Distribute demand: - distribute traffic flows over a meshed motorway network - distribute traffic flows over a network - use the ancillary network - smooth the peaks	- communication - spatial toll modulation - communication - road signing plan - communication - communication - time-dependent toll modulation	1, 2 and 3 1 and 2 1 and 2 4 1, 2 (and 3) 1 and 2 1, 2 and 3
Handle contingencies quickly [reduce Warning and Emergency Call-out Times (WECT)]	- organization including patrols - patrols and WECT on critical points - patrols and WECT	1, 2, 3 and 4 3 and 4 3

This table also refers to the reduction in warning and emergency call-out times, which is not directly involved in the objectives given at the beginning of this annex (optimize capacity supply and distribute demand). However, on sections with traffic problems, an incident that reduces the available capacity may cause considerable disruption, which can be greatly reduced if the initial capacity is quickly restored.

The following tables enable an initial estimation to be made of the impact of planned measures. These effects are not cumulative:

Table 38: Optimization of capacity supply (Reference France)

Objective	Tools	Traffic configuration	Capacity increase (1)	Comments
Optimize capacity supply	Speed control	3	5%	Origin the Netherlands
	Access control	3	3 to 7%	Origin the Netherlands
	Traffic light plans	1, 2 , 3, 4	3 to 5%	By analogy with speed control (the gain is greater on a maladjusted light)
	Local resident access (facilities)	3, 4		Depends greatly on the type of access
	Parking bans	1, 2, 3, 4	1 200 veh/h	If compliance is absolute

(1) These percentages apply to the capacity value in the absence of any operating measure.

Table 39: Breakdown of demand (Reference France)

Objectives	Tools	Traffic configuration	Transfer of demand (1)	Comments
Distribute traffic flows over a motorway network	Communication	1	3 to 8%	Depends greatly on capacity to reach the target
		2	3 to 8%	Depends greatly on capacity to reach the target
		3	2 to 3%	Only one case analyzed
	Communication and spatial toll modulation	1	8% of traffic diverted	Only one known case.
Distribute traffic flows over the network	Communication (e.g. "Bison futé" traffic guidance system)	1		Depends on the proposed network.
		2		Depends on the proposed network.
	Road signing plan	4		Only concerns unfamiliar drivers. It is not easy to determine what is taken into account by the assignment models
Use the ancillary parallel network close to the motorway	Communication	1	5%	Proportional to length of tailback. Nuisance possible on ancillary network
		2	3%	Proportional to length of tailback. Nuisance possible on ancillary network
		3	1 to 3%	Not recommended except with agreement of the local authorities concerned
Level down peaks	Communication	1	2 to 3%	Only one experience assessed
		2		Doubtless similar to the foregoing or even greater
	Communication and time-dependent toll modulation	1		No experience. In principle more than 3% and less than 10%. Note the difficulty in determining what concerns demand elasticity and what concerns communication, necessarily associated.
		2	10%	Note the difficulty in determining what concerns demand elasticity and what concerns communication, necessarily associated.
		3		Note the difficulty in determining what concerns demand elasticity and what concerns communication, necessarily associated.

(1) These percentages concern peak reduction.

IX.3. The key players involved

Table 40 goes beyond the road administration managers to identify the people involved in road development and the provision of associated services, those who use the road and those who are affected by it. The main objectives of these people are in column 2 with the main indicators they use in column 3 and the controls they are able to make in order to achieve their objectives in column 4. In many countries the key players are grouped in organizations that have to fulfill more than one purpose.

Table 40: The key players involved (Reference United Kingdom)

Key players	Objectives	Indicators	Controls
❑ Politicians	❑ Government objectives	❑ Votes ❑ Safety ❑ Environment ❑ Development ❑ Costs	❑ None ❑ National/local objectives ❑ National/local objectives ❑ Transport plan ❑ Budget
❑ Owner	❑ Actual completion	❑ Profitability ratio ❑ Cost ❑ Expected profits	❑ Project management ❑ Project evaluation ❑ Post-construction monitoring
❑ Engineer	❑ Quality scheme	Compliance with: ❑ Standards ❑ Procedures and ❑ Programme	❑ Project review ❑ Consultation ❑ Legal procedures ❑ Standards/specification ❑ Evaluation
❑ Builder	❑ Fulfillment of contract	❑ Construction plan ❑ Budget monitoring	❑ Project management ❑ cost optimization/innovation cost
❑ Operator	❑ Safety ❑ Asset preservation	❑ Maintenance management	❑ Trip quality ❑ Signals and operational equipment ❑ Availability of ancillary services ❑ Traffic interruptions for maintenance
	❑ Traffic operation	❑ Free-flowing traffic ❑ Minimum congestion ❑ Acceptable trip time	❑ Traffic signals ❑ Traffic lights ❑ Traffic control centres

Key players	Objectives	Indicators	Controls
❑ Police	❑ Road safety	❑ Accident processing	❑ Traffic control ❑ Police actions ❑ Control centres ❑ Safety measures
❑ Users	❑ Maximum access ❑ Trip time reliability ❑ Safety of journey ❑ Acceptable cost ❑ Operational emergency aid ❑ Quality of ancillary services	❑ Experiences and personal points of view	❑ Choice of road ❑ Choice of mode ❑ Speed
❑ Those who live and work near the road	❑ Minimum intrusion	❑ Noise level ❑ Air quality ❑ Visual appearance	❑ Providing operators and politicians with context elements
❑ Those concerned by road impacts	❑ Environmental preservation ❑ Improvement of economic spin-offs	❑ Impacts on noise, water, air ❑ Effect on nature, populations, leisure	❑ Providing operators and politicians with context elements

Table 40 (p 183-185) demonstrates a number of key points:

- There are many different quality indicators,
- The relative importance of indicators varies,
- A large number of people are involved, each of whom can only control a few aspects of quality.
- It is desirable to co-ordinate and clarify roles
- The user and those concerned by the road may not be aware of the people and organizations involved in delivery and operation of a road project, nor of their respective roles and interactions

IX.4. The effect of user requirement trends on the road administrations and on the road networks

The following sections IX.4.1, IX.4.2, IX.4.3, outline some of the ideas developed by Committee 4 in its contribution to the introductory report for the session of KL2 on "Users' perceptions".

IX.4.1. Prioritizing resources between investment, maintenance and operation

In countries where the road transport system has reached a good level of maturity, the quality of transport networks has developed in a few decades from a mainly technical value to a more overall value. This value integrates not only purely road-related functions and service to the user, but also the reduction of environmental impacts, land use planning and general project economics. This change has often been accomplished through sustained investment input, particularly for the motorway networks, sometimes to the detriment of rehabilitation and maintenance on existing networks.

Therefore these countries often consider that road administrations must now implement more comprehensive, ambitious policies for managing transport systems and service to the user and must shift the balance of their investment policies from new projects towards the rehabilitation, maintenance and operating of their networks. This conclusion is greatly influenced by environmental concerns which are tending to increase social pressures and administrative and technical constraints on road projects and consequently, on their construction costs.

IX.4.2. Developing communication and transparency

One of the essential dimensions in modernizing a road administration is the development of communication and transparency. The choices of decision-makers have to be explained and clarified. Many different problems have to be solved: traffic congestion, safety, environmental protection, project financing. Whether the road administrations act on the technical aspect through the mechanism of budget choices between investment, maintenance and operations, or on demand through control, management and even traffic restrictions, all these actions need to be explained to the user.

It is essential for today's road administrations to place road transport system management, and more particularly new infrastructure projects or the conservation of existing assets, in the perspective of economic and social cost reductions and sustainable development. This requires the benefits of ongoing projects to be publicly demonstrated and tailored to the real needs of the beneficiaries. The road administrations must achieve this not only through technical justifications but also through communication in the early stages of the new road development process, in order to convince elected representatives and the general public that the project meets a real need and that all reasonable action will be taken to limit its impact on the environment. Prior to the physical existence of a road, people already have a virtual perception of it through the scraps of information they receive. Their perceptions are liable to generate reactions and conflicts that are disproportionate to the realities of the project.

On existing roads where operators are tempted to apply traffic restrictions through various means including regulations or the introduction of charges or toll fees, it is even more necessary, for reasons of equity, to opt for transparency and explain the impartial reasons that have led the road administrations to adopt these solutions. They must ensure that the user is willing to accept them and pay for them.

IX.4.3. Adapting to local contexts

There is an increasing tendency towards rural de-population and urbanization. This concentrates most of the problems in the towns, be they congestion, noise, pollution or hazards for some user categories. And completing even a minor new infrastructure project in highly urbanized areas takes a considerable amount of time and money. Naturally, new infrastructure is not the only solution able to solve traffic problems in urban areas. And the administrations of the different transport modes will be well-advised to co-ordinate their actions if they are to give real force to intermodality and provide a proper public service. It is on these terms that the concept of the transport system will take on its true meaning.

In areas with difficult topography, constraints are also heavy. Road administrations must develop considerable technological know-how and users must accept lower service levels to avoid prohibitive costs.

When measuring the ripple effects of major infrastructures on the regions through which they pass, extremely positive results have been noted in terms of transport cost reduction, by enlarging market regions. But in terms of competition and job-sharing between urban centres, a strengthening of the dominant centres has been recorded. This is a phenomenon that must be taken into account by the road administrations in their efforts to enhance access to some regions in their land use planning policies. Whatever the case, in some more remote rural areas, minimum levels of access and sometimes of transit facilities must be maintained. In the face of reliable low traffic demand, the road administrations may be led to build infrastructures mid-way between motorways and ordinary roads. These infrastructures must be much less expensive than a conventional motorway but with a high service level.

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