Can a transit route be considered outside of its environmental context? Questions raised by an optical guidance system installed on buses

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Abstract: The desire to enhance the attractiveness of public transit services constitutes a factor of development as well as innovation in this field. Such a motivation is typically aimed at improving the performance of systems while holding costs under control. Against this backdrop, we have analyzed a docking assistance device installed on conventional articulated buses and placed into operation in two of France's metropolitan areas. This analysis has targeted the impact of such a system on the bus driving activity, in order to evaluate the extent to which the device actually provides assistance versus the constraints it is capable of introducing for the driver, along with the potential ensuing risks. Results reveal that both the system set-up conditions and environmental characteristics (in particular movements of the roadway's other vehicles and bus passengers) serve to determine the system's capacity to function as a real assistance tool or, on the other hand, to create an obstacle to implementing effective and safe driving techniques.

1. Introduction

The concern in developing public transit services, associated with the drive to trim capital investment expenditures, has given rise to innovative projects and the advent of so-called intermediate vehicles with pneumatic tires, for which the driving function may be controlled thanks to a ground guidance system according to various techniques. One such system, called optical guidance and installed directly onto buses, has been analyzed from the perspective of its effects on the driving task. This analysis has been conducted based on both individual and group interviews held with bus drivers working on transit lines equipped with the optical guidance device. Onboard accompaniment was also included in the investigation, along with video recordings and comparisons drawn from trips completed with the system either activated or deactivated. During these trips, drivers were asked to comment aloud on the driving conditions they were experiencing and to provide details when requested by onboard observers. Transit trips were also undertaken with a group of six bus drivers, by taking turns with the driving task and making mutual comparisons, using an instantaneous and cross-referenced self-assessment format.

2. The optical guidance system

The optical guidance system, developed by Siemens Transportation Systems, consists of a marked line on the pavement, which is identified by an onboard camera mounted on a vehicle, e.g. a bus. When this optical guidance has been activated, vehicle direction is controlled by the route defined on the pavement, with the bus driver maintaining responsibility over vehicle traction and braking, much like driving a tramway. The driver retains the possibility of recovering control of the steering function by moving the steering wheel in any direction, as the system offers very little resistance to such a manual override maneuver. This action signifies however that when the vehicle is controlled by the optical guidance system, the steering wheel remains continuously activated, by virtue of being solidly attached to the entire steering column assembly. This set-up serves as a prerequisite for the quasi-instantaneous reversibility of the driving function, i.e. from the "guided driving" position to the "manual" position. Yet this condition also implies that the driver actually sees the steering wheel turning on its own, in instances where the marked guiding line deviates, without having to perform any driving action.

Some bus drivers may prefer making gestures with their hands while at the wheel as though they were performing magic, while others keep their hands very close to the wheel and even on the wheel itself, without exerting any pressure but maintaining contact nonetheless. Driver preference as regards conduct in the bus depends mostly on the need to ensure ongoing control of the vehicle, but could also reflect the discomfort felt from the lack of utility their hands provide and from the image of shirking work duties that this conjures, as the movement of their feet on the acceleration and brake pedals goes unperceived by transit patrons and even more invisible to those outside the moving bus.

3. Innovation associated with bimodal guided / manual driving

Restricting a vehicle to a predetermined route is obviously nothing new and actually serves as the principle behind all rail transport as well as cable and rack-rail systems, to cite the most widespread. As for the present case, innovation lies in the bimodality of the system, which can shift from the guided mode into a manual mode and *vice versa* just about instantaneously.

3.1 Advantages anticipated from the guidance feature and bimodality

Like with conventional guidance systems, optical guidance meets the expectations that are now part and parcel of a public transit service accessible to the mobility-impaired.

A guidance tool provides the means for performing a docking maneuver at a transit station flush with the platform, in conjunction with vehicles featuring not only a flat and low-lying floor, but also very large capacities since guidance systems are typically associated with double-body articulated buses.

This type of guidance system, which enables instituting bimodal driving, is considered first and foremost as a means for reducing costs in comparison with a light-rail or tramway type of guided transport; consequently, it would appeal in priority to medium-sized urban areas. The savings generated stem from eliminating the need to deviate guided transit itineraries onto underground rail networks and from making use of a conventional depot for the vehicles.

Bimodality is also perceived as a means for "phasing" capital infrastructure investment by beginning with those route sections on which a dedicated lane proves absolutely necessary, yet the connection between dedicated lane and guidance, despite the problems raised, is not mandatory.

4. The system's technical operations

The vehicle's trajectory, or more precisely the trajectory of the vehicle's front axle, is guided by a double dashed line painted on the pavement. The dimensions of these dashed markings are 0.50 x 0.10 m, separated by a linear distance of 0.50 m with a 0.25-m spacing. The onboard camera then detects the road marking and, via an image processing program, the deviation between the position of the front axle and the designated trajectory. An electrical motor actuates the steering column in order to reduce this deviation (see Fig. 1).

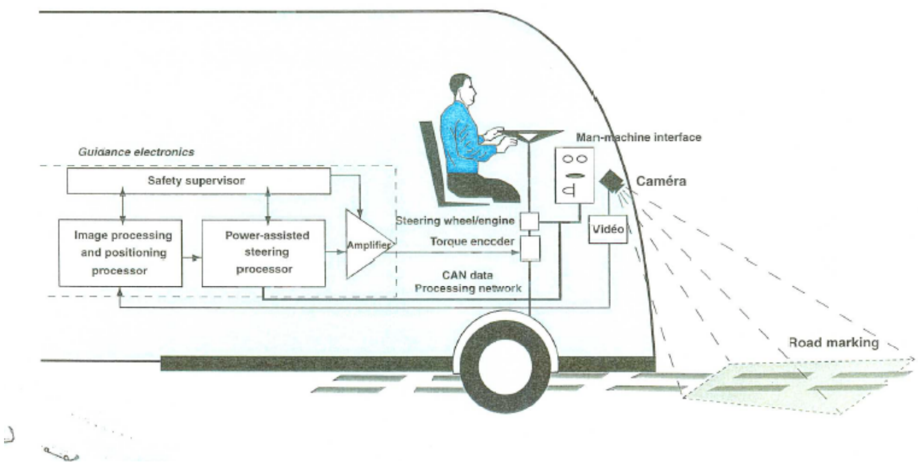

Fig. 1: Operating diagram of the optical guidance system [7]

5. Characteristics of optical guidance implementation in urban areas having opted for this system

Two metropolitan areas in France have, for the time being, elected to equip one of their bus lines with the optical guidance system (see Fig. 2). In the first (A1), which paved the way for such techniques, automated guidance has only been introduced at the level of transit stops and just a portion of the line has currently been fitted. The system operates like a vehicle-docking assistance tool, thereby guaranteeing a constant and limited deviation (gap of 5 to 7 cm) between the platform and the lower part of the vehicle body. This small deviation facilitates access for disabled passengers in wheelchairs as well as for the elderly, young children and strollers. In the second metropolitan area (A2), the guidance system has been installed at a number of stops as a docking-assistance feature and over an approximately 800-m section of line, it is used as a dedicated lane with two stops serviced, whereby the system functions like a tram.

Fig. 2: The "Agora" camera-equipped articulated bus and ground guidance markings

6. How drivers view the system?

In metropolitan area A1 [7], bus drivers are on the whole quite favorable: "*When docking, it's really easy, there's no need to worry about alignment. It's an advantage for the user and for us as well. No problems should ever arise if the speed limit is respected; uncoupling is very rare but does make us lose time when it happens.*" They nonetheless point out that while the guidance system ensures the quality of vehicle docking (alignment with the platform) and that, as such, they can consider it to be an aid, the system also creates stress by still requiring constant attention in order to monitor operating reliability, i.e. always being at the ready to instantaneously take over in manual driving mode: "*The system adds a level of stress to the driving task.*"

As opposed to rail guidance, the risk of losing the guidance function is actually quite high: sunny or rainy weather, fog, rutting on the pavement, drops of oil on the road marking, or as the marking begins to peel off, a really tight curve in the road… These are among the myriad of situations that can lead to "disconnecting" the automated guidance system and necessitate immediate bus driver reaction to maintain the vehicle on a safe course. Yet at the same time, once the system has attained a certain degree of reliability, staying keenly focused becomes difficult: "*At times, the system makes us overly confident and we tend to drop our guard.*" The added stress might also come from attention having to be focused on passenger behavior upon arrival at the stop: "*At the guided stops, even more attention has to be paid to transit users. People are lining up too close to the curb, and despite us alerting them with a signal, they don't really react that much outside the bus.*"

In metropolitan area A2, the drivers interviewed voiced a split opinion about the system, not appreciating its discontinuity, while criticizing its operating rationale. This criticism has not however prevented a majority of drivers from expressing their desire to have the entire line equipped with a dedicated lane by extending the 800-m model section. This apparent paradox may likely be resolved, at least in part, by recognizing that optical guidance was introduced at the same time as the dedicated lane, which by routing bus traffic onto reserved lanes has, from the drivers' perspective, eased the driving task. As regards the equipped stops, the problems encountered are similar to those in A1, with the addition in certain cases of difficulties specific to the system-imposed trajectory when the trajectory "naturally" adopted by drivers during periods of guidance deactivation differs rather substantially.

These points of view, which overlap in certain aspects and differ in others, held by drivers in areas A1 and A2, coupled with the opportunity to conduct a "New technologies" expert evaluation upon request of the A2 transit operator's Executive Board, has led us to observe that what distinguishes a guided driving system from a manual system is the lack of contextual recognition in the guided mode, as opposed to the contextual support provided for driving in the manual mode.

7. Fixed route and imposed speed in the guidance mode vs. variable route and adapted speed in the manual mode

Route and speed constitute the two determinant parameters when driving a road vehicle; bus drivers make the appropriate adjustments to these two parameters depending upon environmental conditions, as determined by an array of factors: type of lane traffic and congestion, proximity of an intersection and transit stop, presence of traffic lights, characteristics of the zone being crossed (e.g. dedicated lane, pedestrian zone, semi-pedestrian traffic, loading zone, schools), weather conditions (e.g. rain, snow, fog, sun from the front, the back or low on the horizon), etc.

In contrast with this ongoing adjustment performed by drivers to optimize vehicle speed and direction, in respecting the comfort requirements of passengers, the optical guidance system fixes both the route and speed (in terms of maximum speed). Guided driving no longer consists of instituting a reflex-oriented approach, by means of incorporating multi-faceted environmental parameters, but rather applying a speed prescription, as calculated in order to merely satisfy the characteristics of the guidance marking and road network profile. "*Once adopted, the guidance system then takes over and imposes its rationale on you*", according to one driver.

7.1 The driving task as a complement to guidance

The guidance alignment, upon entering and exiting a stop, does not depend on the actual conditions of vehicle and pedestrian traffic, but instead is defined once and for all on the basis of urban constraints and problems arising during the calculation. The alignment, which accounts for steering into and out of curves, must in reality "compensate for the response time of the control chain" [3].

For the drivers, any entrance or exit trajectory also integrates the flows of other roadway users. This indifference of the guided alignment to other users presumes, in order to be easily handled, that the dedicated bus lane has been specially designed to ensure adequate protection from flows originating by other users so as to authorize the trajectory independent of such flows. This set-up may entail, for example, choosing an axial lane instead of a lateral one. The significant difference in how bus drivers in the two metropolitan areas have assimilated guidance systems for performing the docking function is partially tied to this aspect.

As a case in point, in metropolitan area A1, the deviation is typically small between the guided route and that taken by drivers when the system has been deactivated, as extra "room" had been introduced in order to guarantee the fluidity and reliability of public transit. Stop ingress and egress thus provides for enhanced continuity during the unguided driving mode, which precedes arrival at the stop and then follows departure; moreover, adjustments were carried out based on feedback obtained from the first few months of operations.

In metropolitan area A2, for a host of reasons and primarily due to the urban constraints present, the markings traced for the guidance system could impose a trajectory different from that used by drivers when operating in the manual driving mode: "*When arriving with the non-guided vehicle, I'll position the bus at the 'B' stop; when coming in with guidance activated, from the very beginning, I'll start, well in fact I'm moving about like this* (hand gestures): *you're getting much closer to the platform and approaching much faster and earlier, I'm actually flush with the platform. Using the guidance system, it's just the opposite.*"

In this instance, the notion of "aid" completely disappears, as the guidance system becomes an additional demand placed upon the driving task; this sentiment has been reflected in the words of an accompanied driver on a guided itinerary, upon approaching a stop where the guidance indication was misaligned with the course a driver would naturally take: "*I've got to position the bus just right for the guidance system.*"

Another driver, making remarks during a group meeting, explained the meaning inherent in this constraint from the perspective of the driving function: "*One thing is certain: the guidance system focuses our attention and influences our way of driving* *towards adapting to the system and away from adapting to our environment, but what always counts in the end is the environment."*

Drivers are thus integrating the "flaws of the guidance system" into their driving strategies, in order to move closer to the conditions of unguided driving:

"Avenue C, before you get to B, that's going too far. The strip runs too far, look it's extending into the left-hand lane. If I see I've got enough room, I'll shut down the guidance system, I'll take a wider angle and I can make it through on the opposite side.
- Yes, and with the system activated, I'm not able to make it through.
- At parking lot M, the system takes us too far. Again the same situation, it's not at all responsive. When there aren't any cars, I'm able to get through, but one more car in the picture and we've got to shift into manual mode or else we're stuck using the guided mode. As for me, I turn the guidance off."

7.2 Speed, trajectory and safety

Imposing a trajectory "as close as possible", via guidance control, paradoxically engenders an added risk borne by bus drivers. Maneuvering room, critical to transit service safety and a reflection of driver expertise, actually vanishes when the guidance system is activated and can even induce practices that unknowingly undermine safety.

"It gave us the reflex of hugging closer to the right and not making the same allowance for safety. The guidance system has obliged us, has forced us rather, to bear this added risk. Since the guidance enabled us to get real close and just watch the rear view to make sure it clears on all sides. Now, we know we've got clearance, so we can roll in at a good clip, but it's not such a good idea to drive fast, since after a while, by constantly working with no margin, as soon as a rear-view mirror or car door extends into the roadway and all of a sudden we're too tight. When driving under more natural conditions, we would introduce a margin and if we felt it necessary to do so, well that means it was indeed necessary.
- You're exactly right. If you drive down the middle of the road, at least you're sure not to be bothered by a door opening.
- A guy said to me the other day when I was driving line 16 and my position was nearly brushing the cars: "Hey, you're traveling much too close to the cars."
- We might tend to think that we're better drivers by being able to get very close, but the margin of safety is being reduced too much."

7.3 Passengers: A determining factor in choosing both trajectory and speed

Passenger comfort and safety are key elements within the driving function. Braking control, in order to avoid overly-abrupt deceleration, and trajectory, to avoid overly-abrupt steering corrections and any sloshing effects, are intended to limit the risks of loss of balance inside the vehicle. Some ground markings could hinder achievement of these objectives, either by reducing the maneuvering room enjoyed by drivers (as indicated above), or by taking excessively-tight curves or by zigzagging in instances where drivers would be able to undertake a smoother maneuver (see Fig. 3): "*To avoid spinning wide on the loop, we've got to really aim well.*"

Fig. 3: Approaching a stop in a system configuration with guidance inactive: Trajectory offset with respect to the guidance marking

Environmental characteristics, at a given point in time, can also create uncomfortable situations, given the conditions present when positioning the vehicle on the track, along with the regulatory obligation for the driver to align with the track from the beginning of the equipped road section: "*We're sometimes required to alter our course entirely in order to clear an obstacle by latching onto the guidance system, since we're not allowed to take control during the maneuver.*" (see Fig. 4).

When these conditions become overly restrictive, drivers breach the rule: "*While operating with the system on when an obstacle appears, I'll disengage from the system manually, clear the obstacle and then get back into guided mode. We're not allowed to, but I believe we're all doing it.*"

Fig. 4: Presence of an obstacle upon approaching a guided zone: Coupling with the guidance system is hindered by the obstacle to be avoided

The passengers being taken into consideration by bus drivers are not just those traveling inside the vehicle, but include those waiting at the stop. From this perspective, the constraints induced by the guidance system would appear to be even greater. Passengers are in fact inclined to get closer to the edge of the platform and drivers are fearful of grazing them if they are moving too quickly towards the platform (see Fig. 5). This concern is shared by drivers on metropolitan area A1 guided routes, even though they feel that the design of the stops and guided trajectory is generally satisfactory.

Fig. 5: Passengers waiting at platforms where pedestrians are walking on sidewalks: Obstacles requiring attention when approaching a stop

Without the guidance function, drivers tend to follow a trajectory that holds the front of the bus away from the platform for as long as possible, performing the platform alignment maneuver as the very last stage with a single turn of the wheel and then bracing the wheels against the platform at an angle: "*If I see folks on the platform, I'll make my approach from further away and then get a bit closer.*"

This technique also makes it possible to achieve perfect alignment, even better than that with the guidance system, with the space between the bottom of the bus body and the platform being reduced to 2 or 3 cm, instead of the 5 to 7 cm using the guided trajectory (see Fig. 6). The trajectories associated with the system, on the other hand, imply beginning the platform approach much earlier and do not take account of the specific waiting conditions on the platform: "*It was already necessary to use a wide berth and then come in tight afterwards to avoid the youngsters. And at C, with the guidance system activated, the arrival is much too tight.*" The system therefore forces drivers to undertake a trajectory that they wouldn't have spontaneously; it induces practices that are at odds with professional instinct.

Fig. 6: Docking at greatest proximity to the platform, with guidance system deactivation: The off-center guidance line shows the best driver performance when driving in the manual mode

8. Discussion topics

Driving an urban transit bus is a complex and demanding activity, in the choice of both trajectory and speed, as well as in incorporating multiple environmental variables. While bus drivers possess a representation of the ideal trajectory and speed over a given route, these parameters are in reality being constantly adjusted to the actual conditions affecting the vehicle's progress. The situation encountered in this context is typically a dynamic one in which "adaptation mechanisms become noteworthy due to situational uncertainties" [4].

The optical guidance system and its quasi-instantaneous reversibility raise the question for bus drivers of how to position their reference situation when the vehicle is being guided. In the guided mode, the logical reference would be that of a tramway whose driving conditions differ substantially from those of a bus, as drivers can only apply brakes to avoid obstacles. This characteristic imposes a set of specific monitoring and anticipation strategies upon drivers, as regards both pedestrian and vehicle behavior. The reversibility of optical guidance leaves open the possibility of associating the deviation in trajectory with an eventual braking action, thereby placing drivers in an ambiguous in-between position: neither bus nor tram. The difficulty of this situation increases once the guided trajectory, which remains disconnected from the actual context, no longer corresponds with what the driver would have chosen under manual conditions, in taking account of the local context. In this case, the system acts to undermine the driver's skills, by creating a conflictual backdrop for the action scene [1], which may serve as a perceived source of driver stress in coping with this system. Research conducted on the tasks of airline pilots and the types of interactions held with increasingly-sophisticated automated systems has helped shed light on the questions raised above. These research efforts have underscored the need for pilots to mentally anticipate the future state of the aircraft [2,5,6]. Not only is it impossible for an automaton to wield this capacity, but moreover reliance on automation could, in certain cases, degrade the pilot's capacities. "Autistic in its implementation, an automated system is isolated from outside reality; it executes according to the programming code with a maniacal rigidity and proves totally inadequate when confronted with a situation not included in its basic programming… In manual piloting mode, intention and movement are inextricably intertwined in the pilot's actions. With the automated pilot activated, human movements can be imitated, but no account can be made of operator's intentions… which remain the vital validation link throughout the duration of an automated system that determines trajectory. Within the scope of overly-sophisticated automated systems, the discontinuity between intention and movement introduces an absurd complexity, as system sophistication thrives within a very specific and formal rationale, which does not correspond with the physical spontaneity of the pilot. The notion of a *hidden effect* may then be surmised inasmuch as the machine-driven cause does not lie in natural harmony with human impulse-driven reactions. This effect produces the absurd complexity that draws the pilot's attention towards the very expensive mental gymnastics of the newly-defined role, which at best discount the advantage of onboard assistance devices and at worst cause a drop in situational awareness." [6]. This *effect* strikes us as being applicable quite germanely to the situation of bus driving assisted by an optical guidance system and accounts for drivers' statements that appear paradoxical, such as: "*At times, the system makes us overly confident and we tend to drop our guard*" and "*The guidance system focuses our attention and influences our way of driving*".

Some of the research carried out on automobile driving, especially that examining the impact of driving-assistance systems on driver behavior and relying on the theory of situated learning [8], also overlaps heavily with our results. Research conducted on the remote-controlled speed regulator system, which resembles optical guidance to the extent that "the driver has the possibility of regaining control at any time by braking or accelerating, disconnecting the system whenever he wishes, or momentarily suspending the system's intervention", has thus shown that drivers are in a way seeking to avoid the system's effects through adopting driving strategies able to anticipate the guidance action. These strategies however are not entirely satisfactory given that: "Bus drivers are merely settling for a compromise, which does not necessarily please them, as in the end (this situation) creates difficulties and even conflicts" with respect to other users [9].

9. Conclusion

Previous data has indicated that several conditions must be fulfilled in order for optical guidance to function like a *bona fide* docking-assistance tool. One of these conditions pertains to the design of transit stops and their periphery, which must be sufficiently protected from traffic flows of other vehicles and pedestrians; moreover, the entrance/exit for the guided portion of the itinerary must be integrated into the continuity of the vehicle trajectory either preceding or following the guidance maneuver. The paradox of this requirement may, once these conditions have been met, be that guidance is no longer necessary for guaranteeing a perfect bus docking flush with the platform. The driver's skill in controlling vehicle trajectory thus becomes "driven" by the quality of the transit stop design, with the platform positioned at an angle allowing the wheels to be wedged and the bus safely in contact with the platform, at a level of performance higher than that permitted by the optical guidance system.

Another vital condition lies in the freedom left for the driver to choose to activate or not the guidance system, i.e. to decide which circumstances are conducive for the system to provide driving assistance. Interviews conducted with drivers and the reflective sessions held in a collective format have revealed that while such is the strategy adopted by the majority of drivers, it is being done so secretly since the transit companies have issued procedures that call for always making use of the guidance system as long as no "critical" circumstance prevents its operations. Recognition of this adept manner for finding an appropriate tradeoff in use of the system also constitutes a resource in the design of an improved system, by virtue of generating discussion on the conditions required for the system to effectively respond to real-world driving constraints.

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