DRIVER DISTRACTION AND INATTENTION
A QUEUING THEORY APPROACH

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ABSTRACT:
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Drivers deal with many different attentional demands of the driving task. Vehicles, pedestrians, animals, broken road surfaces, traffic lights, etc., make independent demands at random; their probabilities varying as a function of time and place and speed. Altogether they constitute a mixed population of 'customers' demanding to be attended to with frequently uncertain levels of urgency. The components of driving compete with themselves for attention and frequently wait in a queue. 'Distraction' and 'inattention' are mathematical necessities of the driving task and might better be abandoned. We need more perjorative words for voluntary map-reading, texting and the like.
KEYWORDS: Distraction, inattention, demand, queuing.

INTRODUCTION
Although driver **distraction** and **inattention** to the driving task have become widely discussed hypothetical causes of automobile accidents, the meanings of the words: 'distraction' and 'inattention' remain uncertain.

BACKGROUND
Lee, Young, and Regan, in 2008, said [1] : "The … distraction definitions that have emerged over the last 20 years (1980, 2000, 2000, and 2001) are consistent with considering distraction as a subset of inattention:

1. Diversion of attention from the driving task that is compelled by an activity or event inside the vehicle.[2]
2. A shift in attention away from stimuli that are critical for safe driving toward stimuli that are not related to safe driving. [3]
3. Any activity that takes the attention of a driver away from the task of driving. [4]
4. Driver distraction occurs when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task. [5]

Despite these prior efforts at definition, in 2004 Sheridan said:

> Distraction from cell phones, navigation systems, information/entertainment systems, and other driver-interactive devices now finding their way into the highway vehicles is a serious national safety concern. However, driver distraction is neither well defined nor well understood. [6]

and proceeded to consider it as a Control Theoretic problem.

My own work on attentional demand in 1967, 1968 analyzed driving as an Information Theoretic problem, and attributed the demand of the road to the statistics and dynamics of the automobile, the roadway, and the traffic, all as seen through the windshield. The word 'distraction' does not appear, although in the opening paragraphs of my paper I commented briefly on things that might adversely occupy some attention of an automobile driver:

> All of us who drive are aware that at times we do not seem to pay very much attention to what we are doing. Drivers tune radios and light cigarettes; they blink and talk to passengers; they listen to news or music. It is said that drivers become "road hypnotized" – staring without seeing at the scene ahead. They look into rearview mirrors and scan for traffic police; they read advertising signs and search for turn-offs. Some of these are legitimate parts of the driving task; most are not. All of them constitute a diversion of attention away from the primary task of controlling a vehicle along a highway in accord with law and custom. [7,8]

In the midst of all this is a stern reality: there is *one* driver, with *one* mind, *one* small area of central vision, *one* pair of hands, and *one* pair of feet. With these tools there is to be constructed, by training and design and economics, a safe system of rules, drivers, vehicles and roads. The driver is expected to see (and hear) whatever is important to see (and hear), and to control speed and direction with the available controls and avoid hitting anything, while, at the same time, getting from A to B at the right time without breaking any of the rules.

It is my contention that such a system is best considered, and most meaningfully analyzed, as a single channel Queue with a service provider—the driver. The service duration and arrival distributions can be calculated from Control Theory and Information Theory, or measured in the field from experiments on occlusion [8] and from field observations such as the 100 car study. [9] Distraction and inattention become Queuing Theoretic problems (and possibly only **one** problem). The driver's attentional and motor capacities are the 'services' provided by the driver (the service channel); and the attentional demands of various aspects of the driving situation, from stray dogs on the road to mad drivers and radar traps, are 'customers' joining the queue to be dealt with by the 'service provider'.

It sounds easy and straightforward. However, when I toil through the analysis of some hypothetical situations I find myself concluding that both *distraction* and *inattention* are ultimately defined in terms of *adverse outcomes.* An irrelevant demand that the driver attends to, in the car or outside of it, is considered to be a violation *only* if there is a *reported* adverse outcome. The same demand, when it does not lead to a report of an adverse outcome, is *not* considered to be a violation. Similarly, there has been inattention only when there was a relevant event or situation to which the driver did not attend *an*d an infraction or other adverse outcome occurred.

WHAT ARE THE CONCURRENT DEMANDS?

Many examinations of automobile accidents have marked 'distraction' (D) as the principal villain. In almost the same breath 'situational awareness' (SA) is also marked as a necessary component of skilled driving. How can we have the latter without some acceptance of the former? Which is more important; the improvement of SA or the reduction of D? Is either of them important?

I argue that the driver of an automobile must deal correctly and in a timely fashion with a number of different kinds of demand. These can arise from a number of sources. Their nature can be clarified (to some degree) by an examination of a few limiting conditions.

Demand Number 1:

Consider first: driving an automobile on a billiard-ball planet with a completely smooth surface and totally uninhabited by any form of life. There is no wind, no hill, no animal or human to cross in front of the car. There is no weather; no rain or fog; no sun to dazzle the driver. There is even no 'place'. The driver is free to drive in any direction, especially since all directions are identical. Despite these extraordinary conditions there may be limits to what the driver is free to do. The car may be dynamically unstable. If no control is exercised, the car, with some degree of divergent instability, might at some speed swerve in its path and overturn. Therefore the driver must exercise speed control and/or steering control, to prevent extreme directional divergence. The timing and duration of such control will depend on the directional stability of the car, on the speed at which it is driven, and on the thresholds and reaction times of the driver.

Thus, even in the absence of both spatial constraints and competitors for space—pedestrians, animals, bicycles, and other cars—there is an intermittent attentional demand placed on the driver to exercise closed loop control over directional divergence that may occur. Crossman discussed it:

> A three-level information-processing model for driver steering control is developed. A key question appears to be what are the actual and feasible minimum repetition rates (or sampling frequencies) at each level. While this certainly depends on the exact forcing function applied at a particular time and on the various thresholds, it seems that level 1 and level 2 could operate with about a 1–1 ratio and a scan rate around 1 per second while level 3 would require perhaps 1/5 the scan rate. Data of Senders et al. are relevant here." (Citing reference 7 of the present paper) [10]

Demand Number 2.
On the same uninteresting planet, if we put a pair of lines with constant separation (a '1-lane road') and demand that the driver stay between the lines, we have the elementary driving situation analyzed by N. Rashevsky in some of the earliest mathematical analyses of automobile driving. In his second paper he said:

> In a previous paper we outlined an approach to the theory of automobile driving for the ideal case of a single car on an empty road. The basic idea of the previous paper is that the driver makes … an angular error … from the exact direction of the road. [Then] ..as, due to that error, the car approaches sufficiently close to the edge of the road, the driver corrects the direction making now the same average error in the opposite sense. Thus the car follows not a straight line but approximately a zigzag line with a very small angle. [11]

Continuing, he assumes that the angular error is a variable with some distribution. This leads not to a zigzag with some specified angle but rather to a wandering path so that the car approaches the edge of the road, after some time at some speed, with a calculable probability distribution. He then asserts:

> ..it is conceivable that through an erroneous act the driver, when for example approaching too closely the right edge, turns the wheel not to the left but to the right, enhancing the error and actually jumping off the road. [11]

One may easily draw from his analysis the conclusion that if a 'distracted' driver failed to note the position of the car at some instance, the car might also, through the driver's failure to act, 'jump' off the road. That places a purely perceptual 'demand' on the driver to note his lateral position on the road and respond appropriately often enough to prevent that event.

Rashevsky went on to comment on the possible effect of distracting stimuli on the reaction time of the driver (i.e., to the approach to the edge of the road) and therefore on the safety of driving.

Thus there are two demands that do not arise from anything external to the driving task itself: one comes from inherent instabilities of the driver-car system, and the other from perceptual and mechanical thresholds (possibly the result of non-linearities such as mechanical dead-spaces) that limit the precision of steering so that inevitable, even though very small, errors integrate over time/distance into significant hazards. Both demands necessitate the same kind of closed-loop perceptual-motor activity.

These two demands can be eliminated only by the addition of full directional control, independent of the driver, as suggested in the following scenario.

Demand Number 3.
If we add to the 'billiard ball world' two rails and place the car on them we relieve the driver of all directional control. The demands for stability and lateral position control disappear and the driver may fall asleep with no risk. An attentional demand arises only if there are intruders,

actual or potential, into the swept space of the 'car'. It is, therefore, important to assess the *probabilities of intrusion* as well as the actual intrusion. If there is an intrusion, the driver must assess the speed of his car and the distance of the intruder and make an appropriate response to change speed.

When there is a *probability of intrusion* attributable to a particular location along the track, the driver must attend in a suitable way, even if no intruder is visible, looking more often in areas of higher probability and less often, if at all, when the probability of intrusion is low.

Demand Number 4.
If there is a speed limit the driver must observe and control speed and/or scan for possible traffic police while exceeding the limit. When driving through an intersection there is a probability that an approaching car will violate the red light and cross into one's path. The glance up the road to the right may inform one that the approaching car is not slowing, but is made with the risk that a nearby pedestrian may choose that moment to cross the road in front of the car. In the vicinity of a playground there is a probability that a ball may bounce into the street and be followed by a child or a dog. I commented on this in 1966 thus:

> If the vehicle is very stable it does not need to be attended to as often as if it were very unstable; and if the uncertainty of steering is small, the driver does not have to look as often as he would if it were large. Similarly, objects at a distance produce less uncertainty than objects close at hand. One would expect that as opposing traffic approaches, the driver must attend more often.. If there are many side streets, driveways, and the like, the probability of cross traffic is high and the driver has to pay more attention... . For example, if one were traversing a road at a constant speed and entered a populated area so that the probability of animal or human entry was high, then the frequency with which one looked at the road would go up. [7]

Demand Number 5
The introduction of technological aids and devices (e.g., IVIS, cellular phones) into the automobile creates another set of demands, some of which are initiated by outside events (the cell phone incoming call) and some by events within the driver. The latter, like initiating a cell phone conversation or texting into a cell phone, have their precursors in map-reading, eating and drinking—and talking—by drivers while moving, since the beginning of driving. Since much of driving is uneventful, a driver's mind will address a wide variety of topics not involving the driving task: *e.g.* , concern about the route; about the fuel remaining, about dinner tonight, etc.

These various demands are relatively simple to analyze. Combining them into a single model is somewhat more speculative. The demands are neither periodic or predictable, they are almost surely uncorrelated. Each of them is a random, or quasi-random, process with its own parameters. The load on the driver is therefore not a simple linear summation of the components. It is not unreasonable to assume that both the durations of attentional acts and the intervals between attentional demands will have exponential distributions, each with its own parameters..

The Attentional Queue

There are 3 major theoretical approaches to the problems of distraction: Information theory and control theory may be useful in defining the distributions of demands. Queuing theory calculates the sizes and the probabilities of waiting times—the times when something that needs attention does not get it because something else is being attended to.

The queue consists of one or more ‘demands’ (things requiring attention) waiting for service (attention) from the ‘server’ (the driver). ‘Distraction’ or ‘inattention’ might be said to exist when a driver *should* have dealt with one attentional demand (that might have shown a potential collision) but is, instead, dealing with some *other* attentional demand. If the attentional demand being dealt with takes more time still another demand may arise and join the waiting line. This is called *distraction*: ‘what should be attended to’ waits for something else to finish being attended to. It is important to note that the demands may all be legitimate parts of the driving task; the fact that the handling of one delays attention to the other does not imply that either is illegitimate; the later demand is merely unlucky.

Lee, et al, (op cit; p. 38) commenting on the overlap of the distributions of demand, states: “Driver distraction is a diversion of attention away from activity critical for safe driving toward competing activity.” I suggest that the competing activity may also be essential for safe driving. The queuing theory model speaks of such competing demands. In this approach the ‘distraction‘ is not always a diversion from ‘duty’; it can be a genuine necessity imposed by external events or probabilities of events.

The Effect of Arrival Rates.

The two principal variables that affect a queue are the service rate (the reciprocal of the mean service time) and the arrival rate (the reciprocal of the mean inter-arrival time) The Pollaczek-Khinchine formula [13] offers a simple solution to part of the question of distraction. It tells us what the expected waiting time (in the queue) will be for a newly arrived demand to a single-server queue with Poisson distribution of inter-arrival times, with a mean time, μA, and an Exponential distribution of service times (how long it takes the driver to attend to the demand) with a mean time, μS. The server is occupied (over the ‘long term’) μS/μA. of the time.

When the server is busy only half the time, the mean *queuing time* equals the mean *service time*, and the mean time *in the system* is equal to twice the service time. A more realistic example would be one in which the mean service time is 1.5 seconds, and the mean interval between new demands is 3 seconds. The driver is busy (on average) only 50% of the time. The mean queuing delay is still 1.5 seconds. That might very well lead to an accident. As μS/μA increases, the mean queuing time increases rapidly. If the server is 90% utilized, i.e., the service time is 90% of the mean inter-arrival intervals, then the mean queuing delay is *nine times the mean service time*. When things get busy they deteriorate rapidly. In real systems there will *always* be queuing delay. If $\mu S/\mu A = 1.0$ the queuing delay grows to infinity

If an accident followed because of delay in attending to a newly arrived demand, the prior demand might be identified as a distraction, even though it had been a legitimate element of the driving task. If demand X is *always* to be satisfied immediately upon entering the 'queue', the driver's business must be limited to that demand, alone. If any other demand is permitted to engage the driver's attention, then there is a finite probability that demand X will wait for some time. That is, when the server is busy only half the time, the mean queueing time equals the mean service time. If the mean time required to attend to a demand were exactly one second, and the driver is engaged only one tenth of the time then the expected waiting time (before being attended to) for demand X is 1.11… second. If such a queuing delay were the maximum acceptable then the driver must be busy (attending to various demands) only one-tenth of the time. It is unlikely that drivers would remain so unoccupied; alternative tasks or pleasures would be engaged in to reduce the probability of utter boredom, sleep, or daydreaming, all in order to restore a reasonable level of occupation, and *some level of 'distraction'* and '*inattention*' as queuing delay will always be termed if an adverse event follows.

CONCLUSION

One might be able to calculate a minimum total risk solution if there were data- and theory-based distributions of a large number of classes of demands, along with assessments of the hazard associated with each as a function of time unattended. Such a task is daunting but not impossible, given the 100 car data base.

Complete elimination of the accidents stemming from 'distraction' or 'inattention' is, of course, impossible.

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