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No Driver Is Alone: A Multicentered Human-Machine System Framework for Multitasking While Driving

Min LIN[a,c] , Mo CHEN[b], Yubo ZHANG[b], Xinying HE[a], and Fan YANG[a,1]
[a] *School of Industrial Design, Guangzhou Academy of Fine Arts, P. R. China*
[b] *School of Mechanical Engineering, Guangzhou City Univ. of Technology, P. R. China*
[c] *Guangdong Key Lab of ID Innovation and Applied Research, P. R. China*

Abstract. Driving is a multitasking process. With the advance of artificial intelligence and driver assistance systems, the tasks of driving go far beyond monitoring one's surroundings and turning the steering wheel. For example, using phones while driving is a common occurrence. However, past studies analyzing driving have only considered a single driver's view, based on the incorrect assumption that the driver is the only person who impacts road safety. This paper proposes a multi-centered human-machine system framework that takes more factors into account, including the drivers of surrounding vehicles and advances in driver assistance technology. An analysis of the scenario of phone calling while driving is performed using the proposed framework, followed by a preliminary evaluation with 18 beginner-level drivers. The results demonstrated the new framework's capability of identifying more approaches both theoretically and practically to better balance the driving and non-driving tasks, compared to the traditional framework. Future research topics with the multi-centered framework, including hierarchical analysis of treatments, collaborative driving support, and information interference are addressed.

Keywords. multitasking, multicentered, human-machine system, HCI, driving

1. Introduction

Intelligent vehicles are a clear trend in the automobile industry [1, 2]. Although autonomous driving has drawn constant attention from both academic and industrial domains [3-5], it still faces many challenges [6-8]. Its current situation is at a stage between full manual driving and complete self-driving: a stage of collaborative driving between human and vehicle. In such a human-vehicle collaboration mode, the driver assistance system (DAS) equipped in a vehicle has the capability of dealing with some driving tasks such as cruise control and forward collision warning (FCW) [9-11]. The application of DAS helps drivers release some cognitive resources used on driving tasks (DT) [12, 13], which to some degree promotes the attractiveness of non-driving tasks (NDT). Therefore, multitasking scenarios while driving will be increasingly common as DAS gets more popular and more powerful, bringing further challenges for human-

[1] Fan Yang, School of Industrial Design, GAFA, 168 Waihuan Xilu, Higher Education Mega Center, Panyu District, Guangzhou, Guangdong, P. R. China 51006; E-mail: fanyang@gzarts.edu.cn.

vehicle interaction.

Indeed, driving itself is a multitasking process [14, 15]. Drivers need to monitor the surroundings while controlling the steering wheel, as well as operating the brake and gas pedals. In every country, driving schools and drivers' license exams have the same purpose—preparing drivers to handle the multiple driving tasks with sufficient proficiency and reaction capacity. However, the addition of NDT makes the multitasking scenarios in driving more complex to analyze. Proficient driving alone becomes insufficient to simultaneously handle DT and NDT without reducing safety. Many earlier studies have shown that phone use while driving significantly increased the occurrence of road accidents [16-19].

Designing an effective human-vehicle interaction system to both provide a reasonable safety assurance and deliver a satisfactory user experience for multitasking driving scenarios is an important issue of the human-vehicle collaborative driving mode. Prohibiting NDT via mandatory regulations appears to be a simple solution for this issue yet proves impractical [19, 20]. Therefore, there is currently no widely accepted solution that would bolster NDT without significantly reducing road safety.

The following part is organized into three sections. In the first section, the driver-centered human-machine system (HMS) is discussed, and a new framework better suited for multitasking driving scenarios is proposed. In the second section, the classic scenario of calling while driving is then analyzed using the new framework, demonstrating the framework's capability of identifying more interested parties and generating more practical treatments, followed by a preliminary evaluation of some treatments. The last section lists three major research directions that need further investigation in the future.

2. Human-Machine System for Multitasking Driving Scenarios

A human-machine system is the combination of humans and the machines they interact with [21], either with intelligence or not. It is composed of three components: the human, the machine, and the surrounding environment. By analyzing the relations among these three components, one will be able to understand the information needed by each involving party and the possible actions based on this information, allowing the realization of appropriate solutions for human-machine interaction [22].

In terms of vehicle related solutions, safety is undoubtedly the most critical consideration. As the automobile industry advances and market competition intensifies, user experience has progressively attracted greater attention in vehicle designs, mostly regarding in-car comfort [23, 24] and user friendliness [25-27]. Nonetheless, HCI (Human-Computer Interaction) research directed at multitasking driving scenarios is still in its early stages, as HMS research nowadays investigates driving performance in multitasking scenarios instead of exploring solutions for better supports on DT and NDT.

2.1. Multitasking Driving Scenarios

Despite driving already being a multitasking process, the term "multitasking" here refers to the simultaneous performance of both driving tasks and non-driving tasks. Driving tasks refer to the activities directly related to car operation such as turning the steering wheel, braking, monitoring the rearview mirrors, changing gears, and route planning. Non-driving tasks refer to a driver's ongoing activities not related to driving, such as taking phone calls, adjusting the in-car air conditioner, changing the volume of the infotainment system, and chatting with other passengers in the car.

Performing NDT while driving is almost inevitable. For example, the pre-installed infotainment system in every car has very little to do with driving but rather serves to fight boredom through content like radio and music. Additionally, continued technological development has made NDT more complicated. In the past, driver interaction with NDT was mostly physical, such as pushing a button or turning a knob. Today, the list of NDT has expanded to include activities like reading and replying to text messages, watching short videos, and playing games. Moreover, they all require more visual attention and higher precision in operation [28, 29].

The main impact from NDT on DT is the competition for a driver's limited cognitive resources [15, 30]. When an NDT demands few resources, a driver will be able to accomplish DT with very little or even no negative influence. On the other hand, when the demand increases, a large impact on driving performance will appear, leading to risks such as lane departure, longer reaction times, or even road crashes [28, 31-33]. Therefore, NDT is not always a safety threat that requires strict regulation, but drivers cannot be given free rein to engage in NDT either. Neither banning NDT nor ignoring NDT is the best choice. Controlling the influences of NDT therefore becomes the logical solution that balances road safety and drivers' needs.

2.2. Driver-Centered HMS Framework

To deal with such a highly complicated scenario, a systematic approach like HMS is helpful in deconstructing and analyzing the issues encountered while multitasking while driving, and further developing an appropriate treatment. Oviedo-Trespalacios et al. (2016) [34] presented an HMS when reviewing the impact of phones on driving performance. The driver, car, phone, and road environment were the four components used for DT and NDT analysis. In this framework, DT included the human-car interface in the car, the human-car controls for the driver to operate, and the information presented by the environment, while NDT focused on the phone, involving the phone interface and the driver's actions on the phone (Figure 1).

The two components, the vehicle and phone, represent the two machines involved in DT and NDT, respectively. But no consideration was taken to identify the components on the human side in the human-machine system. Clearly, such a framework is based on one single person's view which has an implicit assumption that the driver is the only party capable of evaluating the scenario and taking actions. He/she is the center of the framework while the roles of machine and environment are constrained to providing information and receiving instructions. A decade ago, such an assumption was reasonable since the computing power and AI algorithms at that time were still insufficient. But as the situation changed, the driver-centered view became outdated. Both the machine and the environment nowadays can be intelligent. Considering them as two completely passive roles fails to accurately reflect their capabilities. As a result, the relationships among different parties in HMS become more complicated. It is necessary to re-examine each party's role to create a truly complete analysis of multitasking scenarios. Solutions that used to hide in the blind spot may now be discovered.

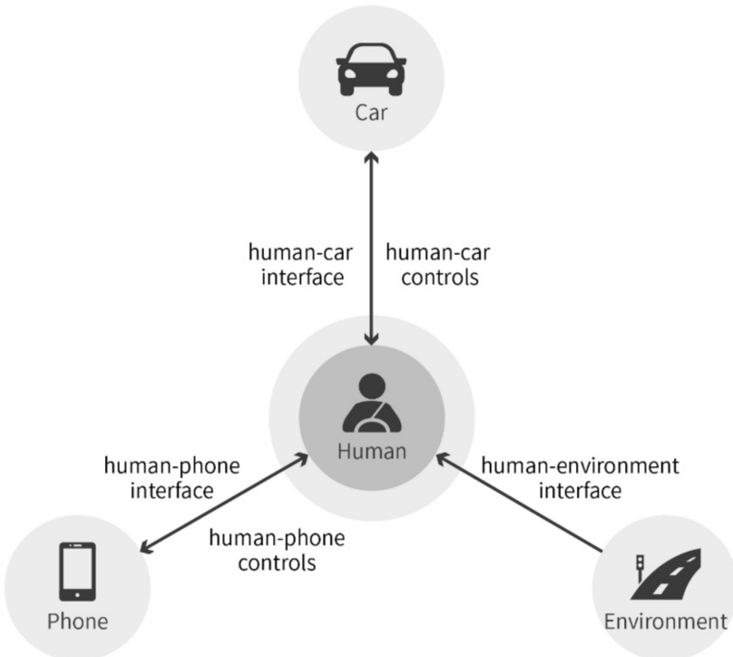

Figure 1. Driver-centered HMS Framework

2.3. Multicentered HMS Framework

When both the machine and environment become intelligent, they become capable of sensing, analyzing, decision-making, and action-taking just like humans. That is, the driver participating in the multitasking scenario is no longer the only center of the HMS. The human, machine, and environment are now multiple centers collaborating to seek best solution. Figure 2 illustrates the parties involved and the complex relations among them.

Firstly, only considering the driver themself is not enough. The result of DT does not solely depend on one single driver, but also the other surrounding drivers. Past studies tended to classify other drivers' behaviors into the environment component. At that time, they were treated more as troublesome obstacles rather than beneficial collaborators because there was little communication or collaboration between the primary driver and the surrounding drivers. But, when the impact of other drivers on road safe is realized, it becomes reasonable to move other drivers from the environment component to the human component. Beyond the driver and the surrounding drivers, there are still more be humans participating in an NDT, such as the other party of a phone call or text message. Therefore, the human component in the multicentered HMS framework should include the primary driver, the surrounding drivers, and the other NDT participants.

Secondly, the machine component is not limited to the primary driver's car and the device used for NDT. As mentioned before, the surrounding cars' performance will affect overall safety as well [35, 36]. In addition to the primary driver's vehicle, the surrounding vehicles should also be included in the framework. Additionally, the number and type of devices used in NDTs need to be re-checked. Using phone conversation as an example, it is apparent that additional devices like headphones, phone holders, or pre-installed handsfree car kit may be involved in the conversation, used to facilitate input and output. Therefore, the machine component in the multicentered HMS framework should include the primary vehicle, the surrounding vehicles, and all the NDT participating devices, not just the primary device.

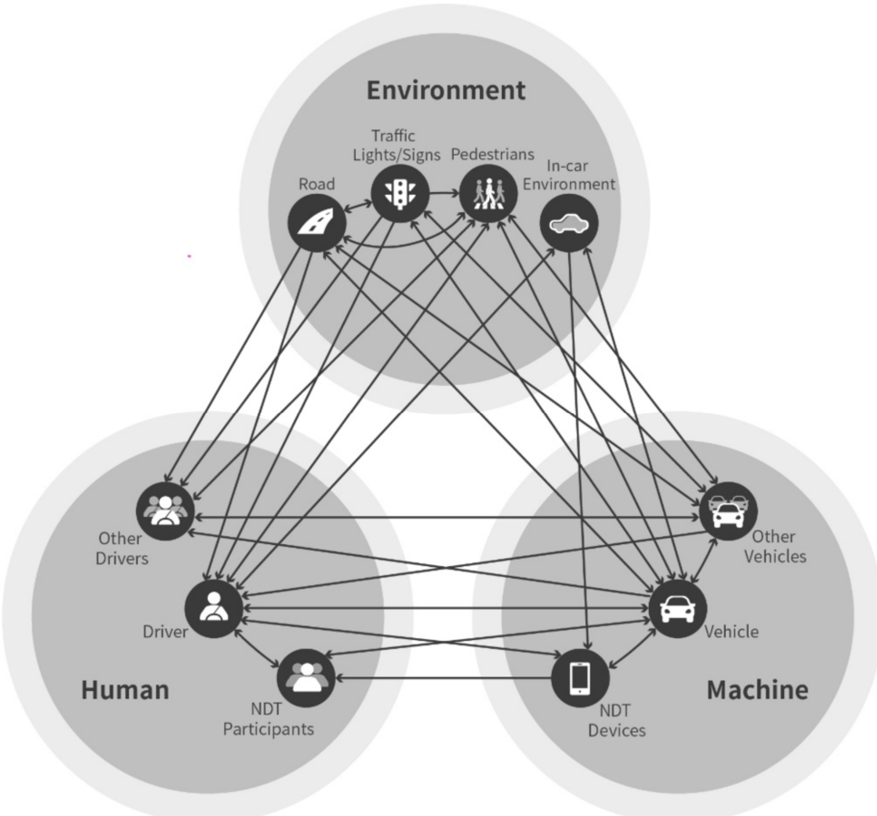

Figure 2. Multicentered HMS Framework

Lastly, the environment component needs expansion as well. Although intelligent roads have not been widely implemented, detailed classification of the road environment is helpful in the analysis of multitasking scenarios and the exploration of a future intelligent traffic system. In general, the road environment can be classified into three categories: pedestrians, the road, and traffic lights/signs. Pedestrians refer to the non-driver road users. They are not considered part of the human component because the separation of people and vehicles is the norm, and therefore pedestrians only have an accidental rather than routine appearance. While the road and traffic lights and signs provide different forms of interaction with road users, both convey traffic-related information to road users. The smarter they are, the more supports they can provide to drivers. In addition, the in-car environment, such as lighting and noise, might affect driving performance [37]. Therefore, the environment component in the multicentered HMS framework should include pedestrians, the road, traffic lights and signs, and in-car environment.

The relations among all these components are much more complicated than that of a driver-centered framework, thus providing greater space to understand the cognitive resource distribution between DT and NDT. An example of utilizing these relations to analyze and seek potential treatments is shown in the next section.

3. Analysis of Phone Calling while Driving

3.1. Relations and Treatments

Calling while driving is the multitasking driving scenario that had received much attention in driver related studies [38-41]. In the driver-centered HMS framework, the driver-phone relation appears to be the only relation that interferes with DT and therefore affects driving safety. Such a limited observation will probably lead to a one-sided conclusion that reducing the cognitive resources occupied by the phone is the only solution, which would then logically imply a policy of complete prohibition on phone use. Unfortunately, this is not true.

Table 1. The relations, treatments, and expected effects in the scenario of phone calling while driving.

Party	Relation Used	Treatment	Expected Effect
Primary Driver	Driver-Phone	Auto-filter nonurgent calls	Reduce phone calls
	Driver-Vehicle	Engage DAS automatically	Reduce driver error
	Vehicle-Road	Inform DAS status	Reduce driver error
	Vehicle-Traffic lights/signs	Use in-car indicators for traffic lights/signs	Reduce neglection of critical information
Caller	Caller-Phone	Wait for driver to call back	Reduce phone calls
	Caller-Vehicle	Receive traffic condition notice	Speed up conversation
	Caller-Driver	Receive “driving” notice	Speed up conversation
Other Drivers	Vehicle-Other vehicles	Receive DAS status	Manage expectation
	Vehicle-Other drivers	Receive “in-call’ status	Manage expectation
Pedestrians	Pedestrians-Vehicle	Receive “in-call” status	Manage expectation

The mistake here is to throw the baby out with the bath water. The driver-phone relation is not the only relation that has potential impacts on DT and NDT. The driver is not alone. The other drivers, the other caller, and the pedestrians all impact road safety during the multitasking period. The multicentered HMS framework provides a map to follow different relations among these parties and look for reasonable supports from each of them. Some relations that can be used to develop possible treatments and their expected effects are listed in Table 1.

To the primary driver, there are at least four pairs of relations that can be utilized to lower the safety risk. The driver-phone relation may help filter nonurgent phone calls so that they can be dealt with later. This treatment may be implemented using an allowlist or some kind of negotiation process to pre-check the call's degree of urgency before passing the request to the driver. The driver-vehicle relation may enable DAS to apply certain restrictions on speed or lane changes to reduce driver error from distraction. If the road is smart, the vehicle-road relation can notify the road to help monitor and carry out these restrictions. Also, to ensure the driver notices critical traffic light and sign information (e.g. lane ending) in time, the vehicle-traffic lights/signs relation may suggest applying some kind of in-car indicators.

To the caller who participates in the NDT, earlier studies had shown that they tended to shorten the phone conversation if they were told the person they were talking with was driving [42-44]. Thus, it is reasonable to notify the caller of the driver's status of driving (via phone-caller relation) or facing a tough traffic condition (via vehicle-caller relation) so that the caller can set an accurate expectation of the conversation process.

For the other drivers surrounding the primary driver, they can benefit from knowing the primary driver's DAS status in an implicit way (via vehicle-other vehicles relation), and from knowing the "in-call" status in an explicit way (via vehicle-other drivers relation). Similar treatments apply for pedestrians (via vehicle-pedestrians relation) as well. By establishing an understandable expectation, the other drivers and the pedestrians can make decisions on how to react to the situation accordingly so their goals can be reached with little or no influence.

With the assistance from these treatments, the NDT devices may not have to redesign their user interface or interaction method dramatically. Some UI treatments such as driving mode can be help, but the collaborative adjustment of the in-car environment—such as muting radio or music via the vehicle-phone—and the vehicle-in-car environment relations may be more effective in reducing the negative impacts of NDT.

This example clearly demonstrates that the multicentered HMS framework can provide more detailed analysis of multitasking driving scenarios and formulate more possible treatments than the driver-centered HMS framework. The driver's limited cognitive resources can therefore be better distributed with the help of various relations among HMS components. More importantly, the new framework changes the relationship between DT and NDT from head-to-head competition into side-by-side collaboration. The research questions on multitasking driving scenarios are finally no longer all equivalent to a safety problem.

3.2. Preliminary Evaluation

Six treatments (Table 2) were carefully phrased to perform a preliminary evaluation. Eighteen Chinese participants (9 males and 9 females) were recruited. Male and female participants were separated into different groups to avoid potential conflicts of views between the genders. All participants were self-considered "newbies" in driving because they did not drive frequently, even those that held a driver's license for several years. Particularly, two screening criteria were applied. All participant must not have more than five years of driving experience, and must not have driven more than 15 days during the last month. Table 3 listed the demographic information of the participants. Beginner-level drivers were used for the evaluation to minimize potential bias—that is, experienced drivers may have preexisting driving habits which may bias their judgment of the proposed treatments.

Table 2. The treatments evaluated and the corresponding median scores.

No.	Treatment	Statement 1	Statement 2
1	Any incoming calls not from the persons in the allowlist will be ignored automatically if you are driving.	4	6.5
2	The caller will be informed automatically that you are driving after he/she makes the call.	7.5	8
3	If there is an incoming call when you are dealing with a complex road condition, the caller will be asked to wait.	8	7.5
4	When you are on the phone, any important information related to road safety will be presented in a more noticeable way than usual.	7.5	8
5	All the vehicles around you will be notified automatically that you are on the phone. (Assume there will be no legal consequences.)	7	6
6	When encountering complex road conditions, a phone conversation will be paused temporarily and resumed afterward automatically.	8	6

Table 3. The demographic information of the participants.

No.	Gender	Age	Experience (months)	No.	Gender	Age	Experience (months)
1	Male	26	48	10	Female	26	60
2	Male	26	45	11	Female	24	6
3	Male	25	60	12	Female	32	52
4	Male	27	6	13	Female	26	10
5	Male	22	19	14	Female	28	9
6	Male	25	32	15	Female	31	34
7	Male	24	39	16	Female	30	45
8	Male	24	52	17	Female	26	52
9	Male	24	9	18	Female	24	45

The treatments were presented one by one. Each treatment was explained verbally and presented in writing to every participant, who were then asked to independently express their viewpoint on two statements by selecting a score for each statement on a

11-point Likert scale. A score of 0 represented “completely disagree” and 10 represented “completely agree”. Statement 1 was “I think the treatment will improve driving safety when I am on the phone”. Statement 2 was “I would like to apply the treatment when I am on the phone while driving”. The treatments and their resulting median scores are shown in Table 2.

Treatment 1, the allowlist treatment, was used as a baseline to examine the validity of the data. Namely, Treatment 1 attempted to wholly prevent the occurrence of multitasking scenarios, whereas the other treatments attempted to provide supports for multitasking. Interpreting the results of Treatment 1, it was therefore not surprising to observe a negative view for Statement 1, as well as a weak tendency in Statement 2 in favor of using it. Conversely, the other five treatments all received a score of 7 or more in Statement 1, indicating that the participants considered them effective in terms of improving driving safety. Such a finding implied the power of the multicentered HMS framework for generating potentially effective treatments, as all proposed treatments outscored Treatment 1. The interest of applying these treatments scored between 6 and 8. Interestingly, Treatment 5 and 6 both scored lower than Treatment 1 in this area, suggesting that the participants were more hesitant to use them despite agreeing that they were more effective. These scores may be due to unfamiliarity with or novelty of some proposed treatments, and such scores may improve when prototypes can be experienced comprehensively in a simulator. Overall, the data exhibited that beginner drivers view the proposed treatments as more effective at improving safety compared to traditional means of regulating NDT. Moreover, the participants showed a willingness to use these methods, indicating viability. Through this preliminary evaluation of the treatments distilled from the analysis based on the multicentered HMS framework, the potential of the proposed framework is not only justified theoretically, but demonstrated practically.

4. Future Research Questions

Driver behavior has been modeled with a three-level hierarchical structure [45, 46], which might be borrowed for classifying the various treatments generated from the multicentered HMS framework. For example, notifying all the involving parties about the primary driver’s status, engaging DAS, and asking the caller to wait are on the strategic, tactical, and operational level respectively. The match between the treatments and the levels of control will help construct the policies of any intelligent DAS for multitasking driving scenarios. Therefore, identifying and sorting the various treatments hierarchically is a research question worth studying.

The cornerstone of the multicentered HMS framework is to consider more parties, including the surrounding vehicles, responsible for overall safety instead of blaming the primary driver for everything. According to this, the supports on information exchange and negotiation among vehicles will make the road system safer. Driving intentions, status, and needs are some of the main information that can be presented in more forms and through more channels. It is very likely to have a collaborative driving support system pre-installed in all future vehicles to utilize this information for better scenario sensing and decision-making. Therefore, collaborative driving support is another research question for the future.

Everything comes with pros and cons. When information exchange and decision-making activities involve more parties, the risk of potential interference increases. For example, when more than one vehicle is under multitasking driving conditions, communication among all vehicles involved may take longer, and the information presented in the same channel by different vehicles may interfere with each other. Therefore, how to reach a consensus effectively and in time, as well as how to pass it to all the parties effectively and in time, needs further investigation.

5. Conclusions

Safety is no doubt the most important concern while driving. Besides the primary driver, there are many components related to road safety in multitasking driving scenarios. The driver-centered HMS framework has failed to perform an effective analysis on the scenario and provide effective solutions. Therefore, the multicentered HMS framework is proposed as a better tool that takes into account not only the primary driver, but also the surrounding drivers, as well as the NDT participants and analyzes in detail the relations among humans, machines, and the environment. The treatments from the analysis aim to better support both DT and NDT and to synergize them to achieve the overarching goal of safety. Although the most common scenario is analyzed as a demonstration to show the power of the proposed framework, more studies are needed to make it applicable and valuable to all multitasking driving scenarios. Hierarchical analysis of treatments, collaborative driving support, and information interference are the three research questions for the future.

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