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Segretariato Generale

Direzione Generale della Ricerca

PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022 PNRR
Prot. P2022KSN9Z

PART A

1. Line of intervention

Main line/Linea Principale

2. Research project title

Global stability of road vehicle motion - STAVE

3. Duration of the project (months)

24 months

4. Strategic emerging Topics - 5. Related Cluster

Strategic emerging topic:	ENVIRONMENT QUALITY
Cluster:	Climate, Energy and Mobility
Sub Cluster:	6. Safe, seamless, smart, inclusive and sustainable mobility services developed/ensured thanks to digital technologies and advanced satellite navigation services.

6. Main ERC field

PE - Physical Sciences and Engineering

7. Other ERC field

LS - Life Sciences

8. ERC subfields

1.	PE7_1 Control engineering
2.	PE8_14 Automotive and rail engineering; multi-/inter-modal transport engineering
3.	PE7_9 Man-machine interfaces

9. Keywords

nº	Testo inglese
1.	vehicle system dynamics
2.	stability and bifurcations
3.	controls
4.	driver model
5.	driving simulator
6.	human-machine-interface HMI

10. Principal Investigator

MASTINU (Surname)	**GIANPIERO** (Name)
Professore Ordinario (Qualification)	
04/08/1960 (Date of birth)	**MSTGPR60M04C933V** (Personal identification code)
Politecnico di MILANO (Organization)	
02 2399 8289 (Phone number)	**gianpiero.mastinu@polimi.it** (E-mail address)

Declarations

☑ I declare that I have not participated as PI in PRIN 2022 call (n. 104 02/02/2022)

☐ I declare that I have participated as associated PI in PRIN 2022 call (n. 104 02/02/2022)

Current funding and applications submitted

Age limits derogation

The principal investigator and or the substitute are over 40 at the time of the publication of the call. They do not intend to benefit from the derogations to the age limits for the amount allocated to under 40 PI;

11. List of research units (RU)

nº	Associated Investigator	Qualification	University/ Research Institution	Registered office (address)	e-mail address
1.	MASTINU Gianpiero	Professore Ordinario	Politecnico di MILANO	Piazza Leonardo da Vinci, 32 - MILANO (MI)	gianpiero.mastinu@polimi.it (adesione completata il 14/11/2022)
2.	GUIGGIANI Massimo	Professore Ordinario	Università di PISA	Lungarno Pacinotti, 43/44 - PISA (PI)	massimo.guiggiani@unipi.it (adesione completata il 24/11/2022)

12 - Substitute Principal Investigator (PI)* (To be identified among one of the associated PIs participating in the project).

GUIGGIANI (Surname)	**MASSIMO** (Name)
Professore Ordinario (Qualification)	
16/08/1956 (Date of birth)	**GGGMSM56M16I726L** (Personal identification code)
Università di PISA (Organization)	
050-2218018 (Phone number)	**massimo.guiggiani@unipi.it** (E-mail address)

13. Brief description of the proposal

The STAVE project aims to increase the active safety of road vehicles to reduce fatalities. STAVE project studies the global stability of the motion of road vehicles with a human or a non-human driver. The aim is to characterize the typical nonlinear behaviors of vehicle-and-driver subject to disturbances like evasive steering maneuvers, wind gust, pot-hole excitation and so on.
The knowledge of such typical behaviours may enable in the future the derivation of proper control laws either for a vehicle with a human driver or for a vehicle without a human driver.
STAVE aims to enable (National or) International Regulatory bodies to issue regulations or standards based on a sound theoretical basis. Education of governmental staff performing homologation of automated vehicles is also a goal of STAVE.
STAVE defines some validated models of vehicle-and driver and performs a bifurcation analysis to characterize typical nonlinear behaviors.
A driving simulator is used to understand and reproduce hard handling maneuvers performed on track.

Both road vehicles and motorsport vehicles are considered to cover all of the possible limit nonlinear behaviors. A number of controls are considered to be used with or without the human driver.
The project is expected to produce inputs for UNECE Regulation 157 (theoretically sound reference to stability within the homologation activity of L3 automated vehicles) and ISO 8855 (edits to the vocabulary). Contacts with such organizations -interested to STAVE results- have been established. A brief course for governmental staff involved in homologation activities is also scheduled.

The graphical abstract of STAVE is reported below.

14. Total cost of the research project identified by items

Associated Investigator	item A.1	item A.2	item B	item C	item D	item E	item F	Total
MASTINU Gianpiero	190.000	0	0	10.000	28.500	0	0	**228.500**
GUIGGIANI Massimo	60.000	0	0	0	9.000	0	0	**69.000**
Total	**250.000**	**0**	**0**	**10.000**	**37.500**	**0**	**0**	**297.500**

N.B. The Item D and TOTAL columns will be filled in automatically

- item A.1: enhancement of months/person of permanent and temporary employees
- item A.2: cost of contracts of non-employees, specifically to recruit
- item B: cost of equipment and tools
- item C: cost of consulting and other services
- item D: overhead
- item E: materials cost
- item F: other costs

PART B

B.1

1. State of the art

STAVE project studies the Stability of the motion of road vehicles with a human or a non-human driver. STAVE contributes both to the UN Sustainable Development Goals #4,#8,#11 and to the European "Green Deal" actions on "Making Transport Sustainable for All".

The stability of the motion of road vehicles is addressed in the literature with many different expressions, namely: active safety, handling behavior, running stability, and so on.

Exactly, what does “stability” mean in our case?

Every common driver feels that the motion of his/her car may become unstable if an impulse is applied by external disturbing forces. Such an impulse or disturbance can be generated by a wind gust, a road irregularity or an impact by another vehicle.
A severe lane-change maneuver can also lead to unstable motion, due to the driver losing control. It is noteworthy that, due to disturbances, non-human drivers may suffer from the same stability problems of humans.

STAVE aims at quantifying the threshold above which a disturbance makes the motion of a road vehicle-and-driver unstable. The threshold is like a safety index characterizing a road vehicle running at a certain speed. The higher the threshold, the higher the safety index, the higher the running safety. This metric may appear simple, but on the contrary, it is extremely complex to define. Many different thresholds do exist, e.g. thresholds on energy or force associated to the disturb, etc. No Carmaker nor National or International Regulatory Body have ever attempted or managed to provide practical information on any threshold.

To compute the mentioned stability thresholds, an in-depth mathematical understanding is needed. Bifurcation Theory, a branch of Systems Theory, is the proposed and proper approach that may provide such thresholds and thus a sound understanding of road vehicle-and-driver stability. Bifurcation Theory deals with the stability of complex systems, defined by differential equations.

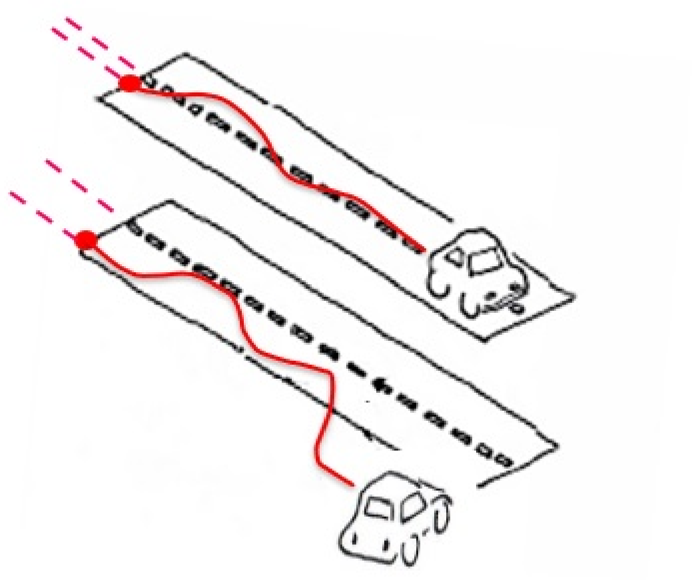
Very few papers in the literature deal effectively with Bifurcation Theory referring to vehicle-and driver stability. The studies started in 1973 [1]. A number of early papers [2-5] used models that were too simplified.

Bifurcation Theory is applied here to nonlinear models of cars and nonlinear models of drivers, either human or not. Bifurcation Theory is important because it allows to produce a taxonomy of typical unstable dynamic behavior of the vehicle-and-driver system, so that engineers can easily classify and understand which kind of stable or unstable motion is occurring. Then, solutions to avoid unstable motion can be derived.

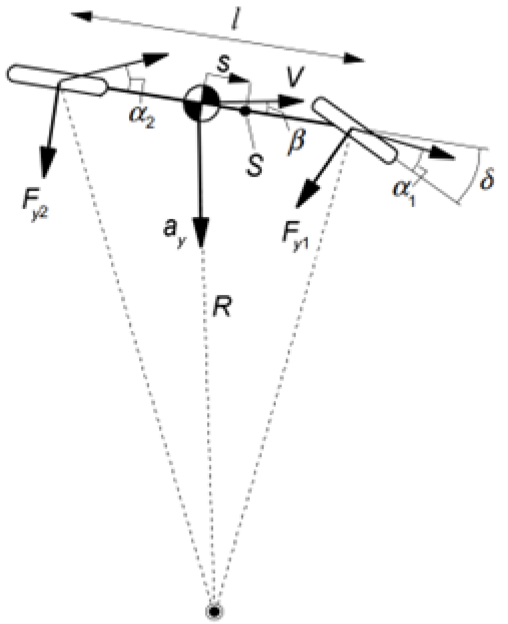
For example, is the motion of the vehicle-and-driver always characterized by a saddle limit cycle, originating from a Hopf bifurcation? Which kind of Hopf bifurcations may occur? Subcritical or supercritical? How controls may change the dynamic behavior of the vehicle-and-driver? Are there only Hopf bifurcations?
A typical unstable motion can be oscillatory with the driver heavily engaged in subsequent steering and counter-steering maneuvers. Another case is the vehicle which goes suddenly into a spin. A wealth of amazing different behavior can be classified.

The classification of unstable motions has never been made for vehicle-and-driver on the sound basis of Bifurcation Theory.
Despite one billion road vehicles are running on the globe, still their stability is not studied with proper scientific tool like Bifurcation Theory.
In a recent book [6], produced by the PI of STAVE for the Int. Ass. of Vehicle System Dynamics, the lack of such classification is evident.
The advent of future automated vehicles will need the concepts developed by STAVE referring to stability of vehicle and non-human driver.

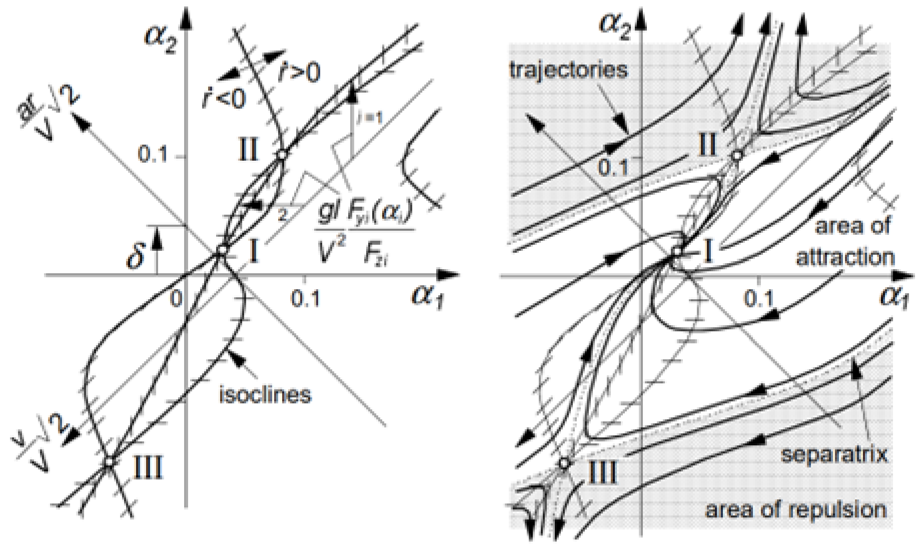
STAVE proposes a strong interdisciplinary research focusing on Vehicle System Dynamics, Mechatronics, Embedded Systems, Automatic Controls, Automotive Engineering, Human Perception, Human Control, Human-Machine-Interface (HMI), with a support from Psichology.
The PI of STAVE has been involved by the European Commission to consult on UN Regulation 157 on SAE Level 3 automated vehicles, the concept of vehicle-and-driver stability was introduced but still it needs consensus and a proper reference within the Regulation!



(a)



(b)



(c)

Fig.1. (a) If the disturbance is small the driver is able to recover the intended motion. If the disturbance is large, the car undergoes into a spin. (b) Simple dynamic model of a road vehicle negotiating a curve. (c) Early attempt made by H Pacejka in 1973 [1] to study how a big disturbance make a vehicle-and-driver unstable, the phase plane is obtained for fixed steering control (fixed steering wheel angle). The phase plane, in which the axes refer to front and rear tyre lateral slips, shows both a stable domain and an unstable domain (gray area).

2. Detailed description of the project: methodologies, objectives, and results that the project aims to achieve; indicate deliverables and milestones outlining the project coherence as to the strategic themes, indicating clear and innovative objectives, setting out the project sector relevance and its positioning with reference to the state of art, describing the role and contribution of each research unit

METHODOLOGIES AND OBJECTIVES

The following objectives allow to exploit properly the methodology of Bifurcation Theory to disclose a new chapter of Vehicle System Dynamics.

Objective 1.

"To develop and validate a mathematical vehicle model to be used within a driving simulator. To find a proper driver model to understand simulations performed at the driving simulator. To simulate vehicle-and-driver motion with an accuracy error on RMS values of relevant state variables of less than 5%."

Vehicle model
We start from known vehicle models, already available at the Politecnico di Milano or University of Pisa. They refer of actual cars (either road or motorsport). We will refine, where needed, the relevant parameters of the models, namely tyres and mass properties which are crucial for accurate simulations.

Fig.2. (a) Actual car taken into consideration (example). (b) Moving laboratory of the Politecnico di Milano to measure tyre characteristics, (c) InTenso system of the Politecnico di Milano to measure the mass properties of cars.

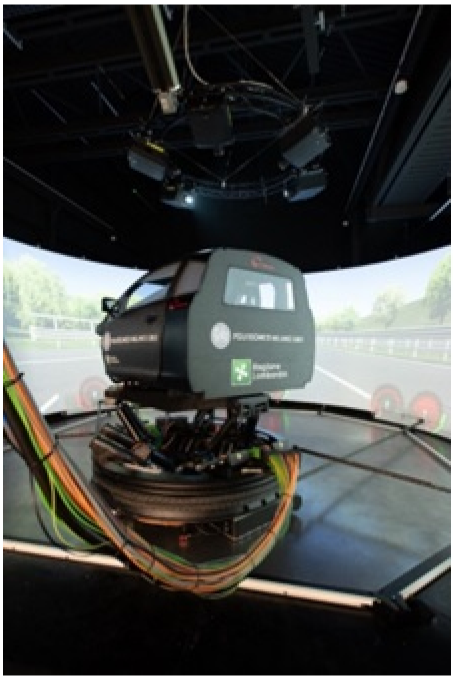
The brakes, tyres and steering system, the elasto-kinematics of the suspension system, the powertrain, the mass distribution of the vehicle, the aerodynamics are modelled at the highest accuracy, allowing deviations of only a few percent for extensive quantities like displacement, velocity, acceleration.
The mathematical vehicle model will include controlled systems like brake-by-wire and steer-by-wire. A non-human driver model will be a part of the mathematical vehicle model, i.e. a path planner for Connected and Automated Vehicle will be considered part of the vehicle mathematical model. The algorithms to make a car automated or autonomous will be implemented.
Real-time simulation is needed for mathematical vehicle models to be used in a driving simulator. This makes developing such models a challenge which STAVE staff has successfully managed [13].
Fast simulations are also crucial to efficiently apply Bifurcation Theory, which requires a large number of integrations of the equations of motion of the road vehicle under study.
STAVE will concentrate on refining mathematical models of vehicle-and-driver which are the most accurate and the quickest from the computational point of view. The combination of these two characteristics is challenging but achievable due to proper exploitation of modern software and hardware.

Driver model
In [5] nearly 200 different driver models have been presented and discussed. A selection of a few driver models will be made in order to be used to understand the stability issues which occur with the actual driver. “Humans are not keen to let themselves be described by mathematical models”. Nonetheless it is not impossible to derive proper paradigms that are adopted by humans during the steering action [12, 13, 15-20].
Many tools are avalibale at the driving simulator of the Politecnico di Milano (www.drismi.polimi.it) for monitoring the driving behaviour, particularly human-machine interface issues (HMI), e.g. EEG, ECG, eye tracking, skin potential measurement. The main tool that will be used to monitor the driver in terms of HMI will be the instrumented steering wheel (ISW) shown in Fig.3. The ISW has been developed for Toyota R&D Labs by a couple of STAVE staff [44].

Driving simulator

STAVE will exploit the dynamic driving simulator of the Politecnico di Milano (www.drismi.polimi.it). The experimental tests on the track to check the stability of vehicle-and-driver involve extremely dangerous maneuvers. So, it is mandatory resorting to driving simulators to study stability and avoid accidents during experimental tests [10,12,15].

A driving simulator is a test facility in which a human performs driver actions and the vehicle motion is simulated in a virtual environment. The cockpit of the car is made oscillating or vibrating to mimic the acceleration acting at the body of the driver in the real world. Sound and vision of the surroundings are artificial as well. Car motion is simulated by a real-time mathematical vehicle model and the numerical output is used to create the artificial environment.

a 

b 

Fig.3. (a) DriSMi - Driving simulator of the Politecnico di Milano. (b) Instrumented steerig wheel (ISW) able to measure the three forces and three moments at each hand, plus the grip (holding force) at each hand [44].

Relevant maneuvers suited for studying vehicle-and-driver stability can be simulated at the driving simulator, e.g. sinusoidal steering with dwell time.

Please notice that data of many vehicles, roads and tracks are already available at the Driving Simulator Laboratory (DriSMi) of the Politecnico di Milano.

The tests at the driving simulator will be supported by the team of Psycometrics experts from University Vita-Salute San Raffaele of Milan who since some time cooperate with STAVE staff [45].

Objective 2.

"To develop and validate a methodology based on Bifurcation Theory for finding the thresholds above which disturbs make a road vehicle-and-driver motion unstable, with an uncertainty of less than 5%."

To assess whether a vehicle-and-driver is stable or not, a methodology is needed to assess the critical levels of disturbs, i.e. the “thresholds” mentioned above. On this topic, a paper on a high impact scientific journal has been recently written by the STAVE PI [5]. The paper shows that thresholds can be measured by exploiting a driving simulator, alternatively they can be computed, provided that a reliable driver model is used.

To compute the thresholds, both the mathematical vehicle model and the driver model are used. Bifurcation Theory is essential for computing thresholds. By means of properly developed software, based on AUTO, Matcont, DDEBifTool, the so-called domain of attraction of a given reference trajectory will be computed [42]. The domain of attraction is the set of disturbances that are associated with the stable running condition of the vehicle-and-driver. Bifurcation Theory is not addressed in a structured way in any commercial software for designing road vehicles. Unfortunately, to date, a sound experimental application of Bifurcation Theory is lacking. STAVE will validate such a new methodology and make it available for implementation into commercial software. This could be the topic of a spin-off company to provide a clear pathway to an important impact of the project.

The thresholds will be studied in different scenarios, depending on reference trajectory and driver model.
To validate the thresholds, the driving simulator will be employed. Bifurcation Theory is essential for defining and interpreting measurements. A disturb will be generated at the driving simulator and the actual human driver will have to react to such an action. A procedure will be defined to generate sets of disturbs.

The computation and/or the measurement of thresholds will refer to the following three cases.

• Vehicle and human driver. Conventional vehicles will be studied in order to define the reference cases, i.e. the thresholds pertaining to today’s vehicles. Reference will be made to motorsport vehicles as well.
We distinguish between automated and autonomous vehicles as described below.

• Vehicle and non-human driver/symbiotic driving. Automated vehicles are driven by both a non-human driver and, at the same time, by the human driver. The stability of such symbiotic driving modality must be properly assessed, in order to ensure safety as well as to optimize control hand-over [40, 41] . A simplified symbiotic driving, i.e. shared driving, already occurs in today’s cars during lane-keeping driving with very basic functionality. The question for STAVE is how to help the driver during panic maneuvers while preserving stability. The final goal is a symbiosis like the one between the rider and the horse for enhanced comfort and safety of the driver.
The Instrumented Steering Wheel (ISW, Fig.3) will help for HMI in-depth analysis during unstable motion occurrence.

• Vehicle and non-human driver/autonomous vehicle. In this case, the driver is just a helpless passenger. The stability depends on how the motion of the car is sensed, controlled and actuated. STAVE will study whether autonomous vehicles can be stable -and safe- under any predictable disturb. According to SAE J3016, we deal here with Level 4 and Level 5 degrees of automation.

Assessing the stability -and safety- of such autonomous vehicles is mandatory for the transfer of responsibility from the driver to the car maker. Such a transfer of responsibility will be viable if and only if the autonomous vehicle will be judged always stable and thus safe. In other words, STAVE will provide basic scientific information regarding the reliability of autonomous vehicles. At the moment the viability of autonomous vehicles, from the point of view of the safety of their interaction with humans, is taken for granted but a sound proof is still not available! The contribution of STAVE may be considered important, or even fundamental, for the existence of future autonomous vehicles.

The limit behaviour of road vehicles is reached in motorsport applications, this is the reason why we take into account such vehicles as well. Path tracking and trajectory synthesis are paramount in motorsport applications to derive optimal driving control laws with the aim to minimize lap times and discover optimal vehicle setups. This activity of path tracking and trajectory sithesis can be transferred to lane change manoeuvre which is extremely important for both Level 3 and Level 4 automated vehicles.
The trajectory synthesis is usually performed ignoring stability and robustness requirements. Also proper tools to specify stability and robustness goals seem lacking.
The typical approach is based on the confidence that a proper feedback controller, built around the nominal trajectory will always be able to cope with modeling errors and disturbances. By properly employing tools from nonlinear system analysis and, specifically, from Bifurcation Theory, STAVE researchers will be able to define stable and robust optimal open-loop trajectories from the outset by properly quantifying, during the synthesis, the effects of disturbances on the vehicle-drive system. This will enhance the intrinsic driveability and the safety of the vehicle.

Objective 3.

"To set paradigms for a new International Standard on vehicle-and-driver stability. Derive inputs for UNECE Regulation 157 (theoretically sound tests on stability within the homologation activity of L3 automated vehicles) and ISO 8855 (edits of the vocabulary referring to stability or vehicle-and-driver). Provide a brief course for governmental staff on nonlinear vehicle dynamics and bifurcation theory"

This objective deals with an actual contribution to improve one existing regulation and one standard. The tests on stability and the correct vocabulary are based on the in-depth understanding of vehicle-and-driver stability (Objective 2). Such understanding provides proper paradigms to decide whether a road vehicle can be stable and safe under any predictable condition.
An implicit goal is to spread the knowledge on vehicle-and-driver stability to Industry, to Universities, to Research Centers, to National Regulatory Bodies (e.g. VDI or the Italian Ministry of Infrastructures and Sustainable Mobility).
This objective is reputed important because International standards that refer to homologation activities for assessing the active safety of road vehicles mention stability in a not proper way [22-34].
UNECE Regulation 157 needs to be improved with respect the problem of stability of vehicle-and-driver. Additionally, governmental officiers (at least the Italian ones) have to be educated on the scientific concepts that pertain to advanced Vehicle System Dynamics and particularly vehicle-and-driver stability.

In the Advisory Board of STAVE we have an officier of the Italian Ministry of Infrastructure and Sustainable Mobility who can advise

on the best way to educate governmental staff.
Additionally In the Advisory Board we have a member of STELLANTIS who declared that STAVE is highly significant for reserarch on HMI and automated vehicles.

The ISO standard on the vocabulary for Vehicle Dynamics (ISO 8855, [25]) mentions “oscillatory stability” and “non-oscillatory instability”. Such expressions are scientifically wrong since it is the motion only that can be oscillatory or non-oscillatory. The STAVE project aims to contribute to the vocabulary in order to align technical concepts of vehicle dynamics to sound theoretical concepts of System Theory related to stability. The noncorrect lexicon (or vocabulary) reveals a need for a broad education action that may start after STAVE main activities will be disclosed.

The final aim is to develop safe conventional vehicles or CAVs (Connected and Automated Vehicles).
STAVE will focus mainly on the stability of cars, but the theory applies to every road vehicle with human or non-human driver.

RESULTS AND DELIVERABLES

The results and deliverables are summarized in the Tab.1 below

Table 1. The STAVE objectives that lead to expected results, substantiated by deliverables.

STAVE objectives, results and deliverables		
Objectives	**Expected results**	**Deliverable**
1. To develop and validate a mathematical vehicle model to be used within a driving simulator. To find a proper driver model to understand simulations performed at the driving simulator. To simulate vehicle-and-driver motion with an accuracy error on rms values of relevant state variables of less than 5%.	Validated mathematical models of vehicles and drivers able to simulate, vehicle-and-driver motion within defined manoeuvres. Data of tyres and mass properties of vehicles. Validated vehicle models suitable for driving simulator tests	Report on vehicle and driver models for stability studies. Due at month 6
2. To develop and validate a methodology based on Bifurcation Theory for finding the thresholds above which disturbs make road vehicle motion unstable, with an uncertainty of less than 5%.	New methods to compute thresholds above which disturbances make a vehicle-and-driver unstable. New methods to deal with stability and path tracking for motorsport and vehicles with human or non-human drivers	Report on Bifurcation Theory applied to Vehicle System Dynamics Due on month 15 Report on stability and path tracking Due on month 22
3. To set paradigms for a new International Standard on vehicle-and-driver stability. Derive inputs for UNECE Regulation 157 (theoretically sound reference to stability within the homologation activity of L3 automated vehicles) and ISO 8855 (edits to the vocabulary referring to stability or vehicle-and-driver).	Guidelines to introduce stability concepts into International Standards Brief course for Governmental staff involved into homologation activities	Report on guidelines to introduce stability concepts into (National or) International Standards and lectures of a brief course on stability of vehicle-and-driver. Due on month 24

MILESTONES OUTLINING THE PROJECT COHERENCE AS TO THE STRATEGIC THEMES

There are four milestones that are introduced in the Gantt chart (see below)

M1 Car and driver model ready – month 6
This milestone checks whether the mathematical models of the car and the driver are ready to perform subsequent Bifurcation Analysis

M2 Bifurcation analysis performed, taxonomy performed, Lyapunov analysis performed – month 14
This milestone checks whether the Bifurcation Analysis has provided useful insights into the vehicle-and-driver nonlinear dynamic behaviour.

M3 Stable path tracking for motorsport or road vehicles performed – month 22
This milestone checks whether a method for trajectory planning and stable path tracking by the driver has been developed, based

on previous Bifurcation analysis. This milestone is particularly important because it gives sound contribution to fulfil the subsequent milestone.

M4 Input for UNECE standard, ISO ready, brief course for governmental staff delivered – month 24
This milestone checks whether the contacts with (National or) International regulatory bodies has been fruitful and inpunts have been given. Additionally higher education of governmental staff will have to be provided by a dedicated brief course.

PROJECT SECTOR RELEVANCE AND ITS POSITIONING WITH REFERENCE TO THE STATE OF ART

According to STAVE scientists, no industrial nor research networks have been established to study the STAVE topics, nor in Japan, nor in the USA, nor in China, … nor in EU!

• The International Association for Vehicle System Dynamics has launched a Colloquium on last 4 March 2022 -organized by the PI of STAVE- to discuss the precise STAVE topics: "Stability and Bifurcations of Vehicle and Driver System", Participants from all over the world have been gathered (https://iavsd.org/events/)

• STAVE aims at enabling OEMs and especially International Regulatory Bodies to define whether a vehicle-and-driver (either human or not) is stable and safe or not.

• STAVE has obtained letters of interest from
>>ISO/TC 22/SC 33/WG 11/Simulation,
>>VDI (the Association of German Engineers),
>>JARI (Japan Automobile Research Institute)
>>European Commission JRC (EC-JRC),
>>Centro Nazionale della Mobilità Sostenibile, spoke on #6 dealing with CCAM cooperative, connecyed and automated vehicles
For sake of space the letter of interest could not be included

• The principal coordinator of STAVE has been involved by European Commission in the development of UN Regulation 157 (Automated Lane Keeping System of cars) and has experienced the lack of scientific knowledge on stability of technical staff. He has proposed to introduce stability issues in the next amendments and such issues are currently under discussion. It is urgent that the concepts on vehicle stability provided by STAVE will enable the correct writing of forthcoming amendments to UN 157 Regulation.

• The principal coordinator of STAVE has delivered a keynote speech at the JSAE AVEC conference held in Atsugi, Japan on 14 September 2022 on "Safe vehicle handling, in any situation? – a continuous topic for vehicle dynamics engineers over time". This topic is exactly the one of STAVE.

• CORDIS does not report EC projects similar to STAVE. STAVE is complementary to the H2020 projects AU-TODRIVE and L3PILOT, Hi-DRIVE as they deal with automated vehicles focusing on the role of drivers.

• ERTRAC, with CCAM, the European Association of Cooperative Connected and Automated Mobility has produced two fundamental publications on automated mobility [35,36]. In [35] a cluster (i.e. a kind of a chapter, is centred on validation. There, the topic of vehicle-and-driver stability is weakly addressed.
In [36] a roadmap is defined for Connected and Automated Vehicles but the topic of stability is not highlighted properly.
In the very important ACEA publication [37] there is still a lacking of dedicated activities on stability.
STAVE, if funded, will interact with CCAM to focus the attention of scientific and technical community on stability issues.

INNOVATIVE ASPECTS OF THE RESEARCH PROGRAMME

Driving simulator
• Original aspects. The research on driving simulators has started many years ago. The new driving simulator of POLIMI, manufactured by VI-G, is state-of-the-art. It has novel features, like cable actuators. The latency is <20 ms which enables stability assessments.
• Innovative aspects. By means of a latest generation driving simulator like the one available at the Politecnico di Milano, stability analyses of the motion of vehicle-and-driver can be made in safe conditions. This will enable to develop both ADAS (Advanced Driving Assistance Systems) and Connected and Automated Vehicles (CAV) exhibiting a stable motion in any predictable condition.

Human Driver Model
• Original aspects. Excellent and original research has been undertaken in the world. Selecting a proper driver model which suits investigations will allow to derive a model of vehicle-and-driver to perform a reliable Bifurcation Analysis. The HMI aspects will be highlighted by means of the ISW depicted in Fig.3.

• Innovative aspects. The fundamental investigation on the stability of the vehicle plus human driver will enable the accurate deployment of automated vehicles (symbiotic driving) and even safer conventional cars.

Bifurcation Theory.
• Original aspects. Often, classical academic books deal with the stability of road vehicles referring to linearized models only…and without taking into account the driver's action! Additionally, the motion of vehicles is slightly disturbed from steady state. If the disturb is strong, which is always the case during accidents or during panic maneuvers, full nonlinear models are to be considered. Recently, scholars have attempted to discover whether vehicles driven by human drivers exhibit some typical nonlinear behaviors, like Hopf bifurcations. They used extremely simple models, far from reality, and they did discover not only Hopf bifurcations, but even chaos. Some authors have been working -and are working- on Bifurcation Theory, but still the contributions on the stability of road vehicles are theoretical and refer to very specific cases.
A couple of STAVE staff applied successfully Bifurcation Theory to the study of road vehicle stability in general. The related papers [4,5,42] have obtained good number of citations, if compared to the citations obtained in the field. The focus was the experimental substantiation of the existence of nonlinear dynamic behavior in real cars and bicycles. A sound experimental substantiation of Bifurcation Theory is still lacking.
Nowadays the stability of cars is studied with a trial-and-error approach. Cars, either virtual or real, are made running on different surfaces in different conditions and, after comprehensive tests, a final judgement is taken on safety. A taxonomy of unstable behavior will be produced by STAVE, exploiting Bifurcation Theory. The thresholds of critical disturbs will be produced as well.
The problem of using complex vehicle systems
• Innovative aspects. The structured approach given by the application of Bifurcation Theory allows to assess ultimately the safety of the many different controlled systems on board of the vehicle.
International Regulatory Bodies will be enabled to rely on a sound theoretical basis to define the possible dangerous motions of vehicle-and-driver.

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3. Detailed description of the project team and planning; indicating the research team components – PI and associated PIs - and their relative expertise/track record, gender equality of the composition, the interrelation and coherence of the team components. RUs- and the feasibility of the project, thus outlining the congruity between objectives, timing and costs

TEAM COMPONENTS, PI AND ASSOCIATED PIS AND THEIR RELATIVE EXPERTISE/TRACK RECORD, GENDER EQUALITY OF THE TEAM COMPOSITION
The following table introduces the project team staff and related tasks as reported in the Gantt chart.

Table 2. Project team description.

	Role	Research Unit	Sub-research unit	Competence	Track record	Task within STAVE
Gianpiero MASTINU Full Prof Gender: male	PI Communication Manager WP3 leader Task 3.1-3.2 leader	Politecnico di Milano	Department of Mechanical Engineering **POLIMI/ MECC**	Vehicle concept design, vehicle system dynamics, human machine interface	330 research products, 26 patents, 5 books, Responsible of the driving simulator of Politecnico di Milano, head of the Scientific Board of the National Cluster of Sustainable Mobility H-index 24/scopus	Coordination of the whole research, Chair of the Advisory Board. Establishing relationships with International regulatory bodies (WP3) Communicating STAVE results
Massimiliano GOBBI Full Prof Gender: male	Staff Exploitation Manager WP1 leader Task 3.3. leader	Politecnico di Milano	Department of Mechanical Engineering **POLIMI/ MECC**	Optimization methods for vehicle design, vehicle testing, motorsport	220 research products, 13 patents, 3 books. Coordinator of the Scientific Board of the Department of Mechanical Engineering H-index 23 (Scopus).	Vehicle-and-driver model defintion (WP1) Education of governmental staff Expliotation of STAVE results
Giorgio PREVIATI Ass. Prof Gender: male	Staff Task 1.1-1.2 and 1.4-1.6 and 2.6 leader	Politecnico di Milano		Driving simulator technology, vehicle dynamic simulations	100 research products, 1 patent, 2 books. H-index 14 (scopus)	Car model derivation Measurement of car data Human-machine interface.
Elena CAMPI Gender: female	Staff	Politecnico di Milano		Artificial Intelligence, Driving Simulator operator, Operational Design Domain specialist	Research staff at DriSMi	Driving simulator experiments, track tests
Fabio DERCOLE Ass. Prof Gender: male	Staff WP2 leader Tasks 2.1-2-3	Politecnico di Milano	Department of Electronics, Information and Bioengineering / Dynamics of Complex Systems **POLIMI/ DEIB/DCS**	Modelling, analysis, and control of complex dynamical systems. Nonlinear dynamics and bifurcation theory. Numerical methods for bifurcation analysis.	50 journal articles, 3 books. H-index 19 (Scopus) President of the Italian Society for Chaos and Complexity.	Coordination of bifurcation analysis computations (WP2)
Alessandro COLOMBO Ass. Prof Gender: male	Staff Tasks 2.2-3 leader	Politecnico di Milano	Department of Electronics, Information and Bioengineering / Dynamics of Complex Systems **POLIMI/ DEIB/DCS**	Modeling of nonlinear dynamical systems, bifurcation analysis, traffic networks, mathematical modeling of human behavior.	53 research products, 3 patents, h-index 17/Scopus, Senior member of the IEEE Intelligent Transportation Systems Society Italy Chapter.	Tassonomy of bifurcations and Lyapunof function investigation
Fabio DELLA ROSSA RTDB Gender: male	Staff Dissemination manager	Politecnico di Milano	Department of Electronics, Information and Bioengineering / Dynamics of Complex Systems **POLIMI/ DEIB/DCS**	Theoretical and numerical bifurcation analysis of nonlinear complex systems.	60 journal articles, 1 book. H-index 16 (Scopus) Executive secretariat of the Italian Society for Chaos and Complexity.	Performing computations related to Bifurcation Analysis Disseminating STAVE results
Giulio PANZANI Ass. Prof Gender: male	Staff Task 1.3 and 2.5 leader	Politecnico di Milano	Department of Electronics, Information and Bioengineering / Controls **POLIMI/ DEIB/CTRL**	Vehicle controls Winner of the Indy Autonomus Challenge the first race between full automated race vehicles (Polimove Team) Holding the world record for maximum speed of a fully automated race vehicle	76 documens in Scopus H-index 13(Scopus)	Definition of the controls within the vehicle-and-driver model Handover maneuvre definition considering stability
Massimo GUIGGIANI Full Prof Gender: male	Staff Task 2.4 leader	Università di Pisa	Dept. of Civil and Industrial Engineering (DICI)	Vehicle dynamics, numerical methods (BEM), generation and kinematics of gears.	150 research products, 5 books. H-index 23 (Scopus). G-index 46 (Scopus)	Coordinating the UNIPI RU Main scientific advisor of the aspects of STAVE related to vehicle dynamics
Marco GABICCINI Ass. Prof Gender: male	Staff Task 2.4	Università di Pisa	Dept. of Civil and Industrial Engineering (DICI)	Vehicle dynamics, robotics manipulation and locomotion, gear analysis, synthesis and optimization, trajectory optimization for complex dynamical systems	79 research products. H-index 24 (Scopus).	Performing computations on trajectory definition and stable path tracking by the vehicle driver (either human or not). Focus on motorsport and road vehicle application (namely lane change)

Unfortunately, only one female staff is in the team. Female psychlogists from the University Vita-Salute San Raffaele are being involved as consultants during tests at the driving simulator.

CONGRUITY BETWEEN OBJECTIVES, TIMING AND COSTS

The Gantt Chart reported below shows not only the link between objectives, work packages and tasks, but it also shows the activities of the Research Units which are four, namely

STAVE GANTT CHART

budget in k€

OBJECTIVES	WPs	TASKS	months	RACI MATRIX POLIMI/MECC	RACI MATRIX POLIMI/DEIB/ST	RACI MATRIX POLIMI/DEIB/CTRL	RACI MATRIX UNIPI	Budget per task	BUDGET PER RESEARCH UNIT POLIMI/MECC	BUDGET PER RESEARCH UNIT POLIMI/DEIB/ST	BUDGET PER RESEARCH UNIT POLIMI/DEIB/CTRL	BUDGET PER RESEARCH UNIT UNIPI	
	WP0	Project Management		R,A	C	C	C	14	14				
OBJ 1	WP1	T1.1 Reference models definition		R,A	I	C	C	5	5				
		T1.2 Data measurement (tyre, mass properties ...)		R,A	I	I	I	5	5				
		T1.3 Control models		C	C	R,A	C	10			10		
		T1.4 Driver model selection		R,A	C	C	C	10	5		5		
		T1.5 Tests on track for model validation and stability asessments		R,A	C	C	C	20	20				
		T1.6 Tests at the driving simulator		R,A	C	C	C	25	25				
OBJ 2	WP2	T2.1 Bifurcation analysis		C	R,A	C	C	33		33			
		T2.2. Tassonomy of bifurcations		C	R,A	C	C	35		35			
		T2.3 Lyapunof function investigation		A	R	I	I	10		10			
		T2.4 Path tracking for motorsport and road vehicles		I	I	C	R,A	40				40	
		T2.5 Handover manoeuvre		I	A	R,A	A	25			10	15	
		T2.6 Tests at the driving simulator		R,A	C	C	C	25	25				
OBJ 3	WP3	T3.1 Meetings with Public bodies or Regulating bodies (JRC, ISO committee		R,A	C	C	C	14	4	4	3	3	
		T3.2 Derivation of preliminary proposal for including correct stability concepts into standards (UNECE 157, ISO 8855)		R,A	C	C	C	18	5	5	3	5	
		T3.3 Brief course on vehicle dynamics to governmental staff		R,A	A	C	A	4	1	1	1	1	
	WP4	Dissemination, Communiation, Explitation, Outreach		R,A	A	A	A	7	2	2	1	2	
			1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24						111	90	33	66	budget per participant
		Milestones	M1 (month 7), M2 (month 15), M3 (month 23)	M4			total	300	4	3	1	2	participants
									28	30	33	33	cost per participant

M1 Car and driver model ready
M2 Biffircation analyss performed, tassonomy performed, Lypunof anallisys performed
M3 Stable path tracking for motorsport or road vehciels performed
M4 Input for UNECE standard, ISO ready, brief couse for grvernmental staff delivered

NOTE

R = Responsible (also recommender)

Those who do the work to complete the task.There is at least one role with a participation type of responsible, although others can be delegated to assist in the work required (see also RASCI below for separately identifying those who participate in a supporting role)

A = Accountable (also approver or final approving authority)

The one ultimately answerable for the correct and thorough completion of the deliverable or task, the one who ensures the prerequisites of the task are met and who delegates the work to those responsible. deliverable.

In other words, an accountable must sign off (approve) work that responsible provides. There must be only one accountable specified for each task or deliverable.

C = Consulted (sometimes consultant or counsel)

Those whose opinions are sought, typically subject-matter experts; and with whom there is two-way communication.

I = Informed (also informee)

Those who are kept up-to-date on progress, often only on completion of the task or deliverable; and with whom there is just one-way communication.

POLIMI/MECC
POLIMI/DEIB/DCS

POLIMI/DEIB/CTRL
UNIPI

The RACI matrix is introduced in the Gantt chart to explain the responsibilities within the tasks.

Table 3 describes the Tasks within the Work Packages and related costs.

Table 3. Description of Tasks within Work Packages. Psychometrics activities by University San Raffaele are funded with a consultancy.

	WP0	Project Management	Task description	Responsible UR	Cost
OBJ 1	WP1	T1.1 Reference models definition	Starting from available car models a couple of multi-body models of cars are chosen for later Bifurcation Theory analyses	POLIMI/MECC	5k€ The cost involves the derivation of mathematical models
		T1.2 Data measurement (tyre, mass properties ...)	In case data are missing or not reliable, car data are measured at the Politecnico di Milano	POLIMI/MECC	5k€ Laboratory activities, the cost is low because POLIMI/MECC has proprietary facilities
		T1.3 Control models	Controlled systems like traction control or yaw rate control are introduced for Bifurcation Theory analysis purposes	POLIMI/DEIB/CTRL	10k€ The problem is to include reasonable control schemes since the actual controls in cars are confidential
		T1.4 Driver model selection	Among the many driver models available in the literaure a limited number of them are selcted for describing track tests and perform later Bifurcation Theory analysis	POLIMI/MECC	10k€ The selection of the proper driver models requires an iteration among simulation and driving simulator activity
		T1.4 Tests on track for model validation and stability assessments	Starting from already available tests performed by PI and STAVE staff, new tests are performed to validate car models and involve manoeuvres in which the driver is particularly activated	POLIMI/MECC	20k€ The cost refers to track rent, car, driver insurance, tyre, etc
		T1.5 Tests at the driving simulator	Tests at the driving simulator to establish a comparison with track tests	POLIMI/MECC	25k€ The cost refers to the lab usage
OBJ 2	WP2	T2.1 Bifurcation analysis	Starting from validated models of vehicle and driver, considering properly the driver's delay, a through analysis is performed aiming to show the existence (or not) of limit cycles and Hopf bifurcations	POLIMI/DEIB/DCS	33k€ A huge amount of man/hour is requested to simulate and analyze vehicle-and-driver dynamic behaviour
		T2.2. Taxonomy of bifurcations	A taxonomy of bifurcations is produced as main vehicle parameters are varied, namely tyre and suspension. The influence of driver parameters is considered as well.	POLIMI/DEIB/DCS	35k€ A huge amount of man/hour is requested to simulate and analyze vehicle-and-driver dynamic behavior
		T2.3 Lyapunov function investigation	The energy balance during the recovery maneuver of the driver is investigated	POLIMI/DEIB/DCS	10k€ Simulations and analytical derivation of mathematical expressions
		T2.4 Path tracking for motorsport and road vehicles	The definition of stable and robust path for motorsport application and lane-change maneuvers are derived Lane change of road vehicle is considered as well	UNIPI	40k€ The derivation involves defining and testing in LAPSIM research codes stability and robustness requirements as properly conceived goal functions and/or constraints
		T2.5 Handover manoeuver	The handover manoeuver is studied in order to provide the driver a vehicle which is far from the boundaries of the stable domain of attraction.	POLIMI/DEIB/CTRL UNIPI	25k€ The derivation is particularly tricky
		T2.6 Tests at the driving simulator	Tests at the driving simulator to establish a comparison with analyses of Bifurcation Theory	POLIMI/MECC	25k€ The cost refers to the lab usage
OBJ 3	WP3	T3.1 Meetings with Public bodies or Regulating bodies (JRC, UNECE ISO committee)	The relevant people who have coordinated the issuing of UNECE Regulation 157 and the ISO 8855 will be met. Discussions on improvements will be made.	ALL	14k€ Trips to meet people from Int. Organization and preparation activities
		T3.2 Derivation of preliminary proposal for including correct stability concepts into standards	Writing of editings	ALL	18k€ A huge amount of work for studying existing standard and propose editings
		T3.3 Brief course on vehicle dynamics to governmental staff	A two-day course will give to Italian Governmental staff information on complex issues related on stability of vehicle-and-driver	ALL	4k€ Organization of brief course
	WP4	Dissemination, Communiation, Explitation, Outreach	Managers are activated to do increase the visibility and impact of STAVE		7k€ Mostly co-financing of open access publishing

DESCRIPTION OF FACILITIES

The main facility at Politecnico di Milano comprises a cable-driven driving simulator with nine degrees of freedom and full-scale cockpit. A base platform provides the low frequency longitudinal, lateral and yaw motions (up to 3Hz, 4x4 m working space, ±60° yaw rotation). The cockpit is connected to the base platform by a hexapod which provides high frequency motions up to 30 Hz for all six d.o.f.. Six shakers are connected to the cockpit to provide NVH frequencies. The system is completed by active HM interfaces as seat, safe belts, steering wheel and brakes. The simulation environment is able to reproduce real world situations, including traffic conditions. The simulator is equipped with ECG and camera for driver monitoring. Driver commands are also acquired. Acquisition channels are available for additional sensors, such as instrumented steering wheel, EEG, accelerometers, etc.
The driving simulator has superior and unsurpassed performance for lane change, since the working space is wide enough to reproduce the full maneuver.

The DataCloud Interdepartmental Laboratory Project focuses on data analysis and machine learning techniques to find, propose, and apply new, precise solutions to complex problems in various scientific and application fields. DataCloud’s goal is to set up a shared, high-performance calculation infrastructure. The main focus will be on the analysis of medical and biological data acquired on the driving simulator.

SCIENTIFIC ADVISORY BOARD

An Advisory Scientific Board for STAVE has been established in order to support the scientific production of STAVE. The Board is composed by the following people:

Ing. Luisa Andreone, from Stellantis/product development advanced-technology & pre-development programs collaboration & networks CRF; EUCAR Leader of the Expert Group "Driver Vehicle Dialogue" on human factors and human vehicle interaction.
Ing. Domenico Minniti, executive from “Uffici Motorizzazione Civile DGT Nord Ovest - Centro prove autoveicoli”, Milan, Italian Ministry of Infrastructure and Sustainable Mobility
Ing. Biagio Ciuffo, from JRC/European Commission
Prof. Manfred Ploechl, TU Wien, expert of driver models and nonlinear automotive controls, Secretary General of the International Association of Vehicle System Dynamics, Editor of Vehicle System Dynamics

The Board meets once per year and acts as an advisor for the STAVE Consortium.

PROJECT MANAGEMENT

The administration management will be carried out by dr Chiara Erroi of the Department of Mechanical Engineering of the Politecnico di Milano. The PI, prof. Mastinu will be in constant contact with Dr. Erroi to solve any reporting problem.

The scientific management is based on structure, procedures, and roles of research staff that are described below.
The scientific management actors are the Principal Investigator (PI), the Executive Board (EB), Work Package leaders (WPLs), the STAVE Assembly.
The PI is prof. G Mastinu who coordinates the project.
The Executive Board (EB) is composed from PI, associated PI and WP leaders. The primary function of the EB is to ensure achieving the project objectives by coordinating collaboration and integration between WPs.
The WPLs undertake the day-to-day coordination including planning, monitoring and control of all tasks within their respective work package.
Task leaders (TLs) are Supervised by the WPLs. Each TL will prepare a detailed work plan. During the task, the TL is responsible for achieving the specified milestones and generating specific deliverables within the given timeframe.
The STAVE Assembly is composed by all the STAVE staff and make final decisions on any topic referring to STAVE running, by voting on a democratic basis.

RISK ANALYSIS OF THE PROJECT

Table 4. Risk analysis

Risk	Description	WP	Likelihood (1-3) 1:low 2:medium 3:high	Impact (1-3) 1:low 2:medium 3:high	Risk Level (1-9) 1:low 9:high	Proposed mitigation measures	Effect of mitigation measures
R1	Difficulty of getting approval from ethics committee for testing with humans	1,2	1	3	3	The DriSMi staff have extensive experience in experiments with human subjects. The project will be submitted on time to make changes if necessary.	No delay
R2	Car model or car data difficult to be obtained	1	1	3	3	Change car. Change model.	Small delay or no delay
R3	Driver model hard to be selected	1	2	3	6	Consult with prof. Ploechl, one of the Advisory Board people, one of the major expert in the field at a global level	Small delay or no delay
R4	Problem in defining the disturbs acting during relevant manoeuvres	2	1	3	3	Define a more simplified proper scheme according to existing schemes already defined by SAE	Small delay or no delay
R5	Difficulty of recruiting subjects	1,2	1	3	3	Focus on PoliMi's students or colleagues	Small delay or no delay
R6	Inability of subjects to drive, due to nausea or discomfort	1,2	3	3	9	Recovery breaks will be included in the testing procedure to limit this problem. Drivers known to DriSMi that do not feel sick to be involved.	Small delay or no delay
R7	Bifurcation Theory unable to provide sound results applicable to vehicle-and-driver	2	2	3	6	Simplify vehicle models, simplify driver model, find simple situation that are anyway relevant for describing stability	Recoverable delay
R8	Reduced interest on STAVE results by International Regulatory bodies (UN-ECE, ISO)	3	1	3	3	Involve national or overseas organizations like VDI or JARI (who signed a letter of endorsement for STAVE) in order to increase interest on STAVE. Improve Communication activity involving CCAM	Limited delay

ETHICS ISSUES

SAVE respects fundamental ethics principles, including those reflected in the Charter of Fundamental Rights of the European Union. These principles refer to

Dignity
Freedoms
Equality
Solidarity
Citizens' rights
Justice

Research will be carried out with the involvement of human drives whose perfomance will be assessed by STAVE staff.
The participation will be on a voluntary basis. Medical insurance will be issued for drivers at the Driving Simulator. Data on human driver behaviour will be collected during sessions at the Driving Simulator. No personal sensitive data will be collected. Preferably, aggregated data will be presented, so that no individual personal data will be shown. Data will be always anonymous and will be released for exclusive scientific studies. Other unintended use will be forbidden. Any photo of drivers will be made anonymous, or special permission will be asked to driver for publishing his/her image.
STAVE staff will be particularly sensitive to Gender Issues and promote equal treatment of any human being either at the level of subjects (drivers) or research fellows.

The test procedures will be submitted for approval to the Ethics Committee of the Politecnico di Milano (https://www.polimi.it/en/scientific-research/contacts/ethical-committee/) The Committee will ensure that the research takes will place in accordance with the ethical principles defined by international and Italian legislation and by the University's Ethics Code. The presence in the project of a team of expert psychologists ensures that the activity protocols of the subjects have been designed in the utmost respect of ethical norms. The same team is in charge of monitoring all the performance of the tests.
The HL4IT activities relating to: data or personal marks detection, tests and validation of new measurement and/or action devices, interviews, observations, psychophysiological measurement parameters will be strictly monitored by the Ethics Committee.

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4. Detailed description of the Project impact, as such; indicating knowledge improvements, technological innovation and/or industrial applications, scientific community reinforcement, level of research internationalization, dissemination and exploitation of the results

KNOWLEDGE IMPROVEMENTS

The strengthening of EU innovation capacity by knowledge improvement is obtained by providing a pre-competitive unreferenced way to study the stability of vehicle-and-driver, based on the mathematical approach of Bifurcation Theory.

R&D departments of automotive SMEs or Big Industries need fellows that know how implementing the specific scientific knowledge on Bifurcation Theory into a complex system like a modern vehicle. STAVE is committed to increase knowledge for improving the mobility of the future.

TECHNOLOGICAL INNOVATION /AND OR INDUSTRIAL APPLICATION

One of the main causes of road fatalities is the loss of vehicle-and-driver stability [6,9]. Drivers lose control due to instability. In 2015, a total of 26134 road traffic deaths and 1.09 million road accidents causing personal injuries occurred on EU-28 roads [11]. Nearly one million deaths are recorded yearly in the world due to road accidents. STAVE aims at staving road accidents by providing a classification of possible unstable motions of vehicle-and-driver.

Around the world, driving simulators and test tracks are increasingly used. The aim is to test extensively and holistically Connected and Automated Vehicles (CAV) or conventional road vehicles. Huge investments are being made. The EU is by far the world’s largest investor in automotive R&D with €53.8 billion in 2017 [21].
STAVE aims at increasing the efficiency of automotive R&D investments, by avoiding extensive and unnecessary testing on track. Actually, the fundamental knowledge produced by STAVE will help the design of experimental and simulation methods efficiently ensuring stability of CAVs.

The EU Mobility and Automotive Industry provides jobs for 13.3 million people and accounts for 5% of the EU’s GDP7 [11]. In 2022-26 an average yearly production of 80 million vehicles is expected in the world. With a vehicle production share of nearly 20%, the role of Western Europe is weakening, and the trend is negative.
A countermeasure for such a trend is to train -as soon as possible- the very best automotive researchers, expert on key topics like Bifurcation Theory, Driving Simulator Technology, human and non-human drivers (i.e. CAVs).
STAVE has impact on the 7000 billion Euro of the world yearly turnover related to transport [11].

The stakeholders (users) that could ‘benefit from’ and ‘apply’ the results of STAVE are: European society, (National or) International Regulatory Bodies, Carmakers, Automotive Suppliers.
• EU needs to foster growth. Economic theories teach that this can be obtained by fostering Transport. Safe Transport is a key topic for EU. Safe Transport implies a proper knowledge on vehicle-and-driver (either human or not) stability, the topic of STAVE. Studying vehicle-and-driver stability requires the mentioned scientific skills on Bifurcation Theory, Driving Simulator Technology together with different disciplines, spanning from Bioengineering to Psychology and more.
• National or International Regulatory Bodies e.g. Italian Ministry of Transport (MIMS), VDI -Association of German Engineers- or ISO Technical Committee on Simulation need to define Regulations for establishing how to check or design the safe running of future automated vehicles. This requires a taxonomy, i.e. a classification of vehicle-and-driver instability modes, which is the topic of STAVE. MIMS VDI, ISO endorse STAVE. The European Commission-JRC (EC-JRC) is interested to explore the possibility to exploit the STAVE project results.
• Carmakers, especially European ones, require immediately smart engineers to solve the problem of safe running of Connected and Automated Vehicles. The risk of Carmakers is to spend a huge amount of money for experimental research that could be avoided by a better understanding of the phenomenon of losing control of the car by the driver (either human or not). The famous publication by ACEA “Safety first for automated driving” needs STAVE results.
• Automotive Suppliers have the same unmet needs of Carmakers, and will benefit from the same international, interdisciplinary and intersectoral training that STAVE aims to provide. EU Automotive Suppliers are the strongest in the world and must be strengthened further (source: www.clepa.eu).

Referring to the economic impact of industrial application, by 2030, in the EU, approximately 30 million vehicles/year will be equipped with SAE Level 3 automation whose unitary value could be nearly 5000€. Thus 150 billion €/year could be the turnover on which STAVE has a non-negligible impact due to having fostered the formulation of Regulations or Standards [11, 22-34].
Without STAVE research output, automated vehicles (SAE Level 3 and 4) and autonomous vehicles (SAE Level 5) will hardly be developed efficiently. This explains why STAVE results are urgently needed by Industry.

The expected societal impacts, referring to United Nations Sustainable Development Goals are as follows

UN SDG #8 on decent work and economic growth STAVE allows the development in Europe of a technological leadership on future automated vehicles with an impact on the 13.3 million employees in the automotive sector (https://ec.europa.eu/growth).
UN SDG #11 on sustainable cities and communities According to European Commission, by 2050 zero acci-dents will have to be achieved in EU, this goal can be reached by the extended use of automated vehicles, studied by STAVE. STAVE will contribute to eliminating almost 25000 deaths/year in EU, with an estimated associated cost of 25 billion Euro/year. In the world, nearly half of 1 million yearly fatal accidents are due to the driver. If STAVE will just succeed in reducing by a factor 1/1000 such fatalities, some 500 lives will be saved per year in the future.
Automated vehicles can reduce emissions making traffic more fluid. The CO2 savings are hard to be quantified but contribute to the Green Deal “Fit for 55” defined by the European Commission in view of 2035.

SCIENTIFIC REINFORCEMENT AND LEVEL OF RESEARCH INTERNATIONALIZATION

STAVE will provide authoritative papers on:
1. usage of driving simulators for vehicle-and-driver stability,
2. accurate human driver models for studying vehicle-and-driver stability,
3. thresholds above which a disturb makes unstable vehicle-and-driver motion,
4. paradigms for a new International Standard on vehicle-and-driver stability.
5. approaches for the robust open-loop stable trajectory synthesis in motorsport application.

Many of the future papers on driving simulators or on driver models for stability studies or on automated vehicles are expected to cite the scientific results obtained by STAVE.

Particularly, proving -theoretically and experimentally- that the driver may introduce limit cycles influencing vehicle stability will be the core concept by STAVE, to be acknowledged by the scientific community.

The major scientific impact by STAVE will be introducing a fully new chapter of Vehicle System Dynamics, dealing with “Non-linear Behavior of Vehicle and Driver, either human or not”. This chapter will be supplemented in the coming years by experts from Academia and from Industry.
The outcome of STAVE will be simply providing the proper scientific tools for the development of automated vehicles.
After 5 years STAVE will be finished, at least 100 citations are expected to be gained by each scientist of STAVE.

At a world level, high scientific reputation of EU on Connected and Automated Vehicles will be generated by STAVE. Open Innovation sponsored by Cluster organizations endorsing STAVE perfectly matches with the pre-competitive re-search of STAVE.
In particular, STAVE will enable Italy to become a world recognized area where advanced vehicle system dynamics are addressed scientifically. This will let Italy gain international recognition.

The books by two STAVE staffs [6,7] clarify the vehicle dynamics scientific issues that are needed to study vehicle-and-driver stability.

DISSEMINATION AND EXPLOITATION

- A Dissemination Manager is chosen among RU staff.
- A Communication Manager is chosen among RU staff. He/she will be in charge of the Outreach activities as well.
- An Exploitation Manager is chosen among RU staff

The Tab.5 below summarizes the dissemination, communication and exploitation actions to allow STAVE to impact on society.

Tab.5. Dissemination, Communication and Exploitation by STAVE

Impact or Outcomes boosting measures		
Dissemination targets	**Communication targets**	**Exploitation**
At least 1 paper per STAVE staff delivered at international conference (total of at least 8 papers) At least 1 paper on scientific journals, per STAVE staff, (at least 8papers) e.g. Vehicle System Dynamics, ASME Journals, Vehicles, IMechE Journals, etc	At least: 1 TV interview, 1 Newspaper interview, 3 YT videos 2 Cluster briefs, 3 Linked-in posts, 1 Website 1 webinar 2 posts with specialized magazines	Use in motorsport activities of the new method to obtain vehicle-and-driver stability
		At least 1 patent or utility model
Organization of the international congress **AVEC 24** **in Milan**		**Proposal for new (VDI), ISO or UN Regulations**

Fig.4. International conference that will be organized in Milan during 2024, fully centred on STAVE topics.

Referring to outreach activities, the following actions will be undertaken
-Involvement of high schools
-Local initiatives related to the Researchers' Night or Open Days will be joined. Feedback from visitors will be collected and processed to better tune further STAVE communication activities.
-Two automotive specialized magazines (e.g.: QUATTRORUOTE, AUTOTECNICA) will be contacted and invited to start a discussion with their readers on STAVE ongoing results. People will be contacted via the social media channels belonging to the magazines. The feedback will be processed to refine further STAVE communication.

The Intellectual Property Rights (IPR) will be shared between the inventors and the organizations to which inventors belong. The IPR offices of Technology Transfer Offices (TTO) of Universities will manage exploitation plans. The Exploitation Manager will supervise and control the patent production.

5. Financial aspects: costs of each research unit

nº		Funds of the Ministry of University and Research (euro)
1.	MASTINU Gianpiero	228.500
2.	GUIGGIANI Massimo	69.000
		297.500

N.B. The fields will be filled in automatically

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[20] Carrera Akutain X, Ono K, Comolli F, Gobbi M, Mastinu G, Further understanding of steering feedback and driver behavior through the application of an instrumented steering wheel, ATZ, 10th International Munich Chassis Symposium 2019 pp 481-502
[21] ACEA Pocket Guide 2020-2021
[22] ISO 1176 Road vehicles — Masses — Vocabulary and codes
[23] ISO 2416 Passenger cars — Mass distribution
[24] ISO 3833 Road vehicles — Types — Terms and definitions
[25] ISO 8855 Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary

[26] ISO 4138 Passenger cars — Steady-state circular driving behaviour — Open-loop test method
[27] ISO 7401 Road vehicles — Lateral transient response test methods — Openloop test methods
[28] ISO 8725 Road vehicles — Transient open-loop response test method with one period of sinusoidal input
[29] ISO/TR 8726 Road vehicles — Transient open-loop response test method with pseudo-random steering input
[30] SAE J266 Steady-State Directional Control Test Procedures for Passenger Cars and Light Truck
[31] ISO 19364, Passenger cars — Vehicle dynamic simulation and validation — Steady-state circular driving behaviour
[32] ISO 19365 Passenger cars — Validation of vehicle dynamic simulation — Sine with dwell stability control testing
[33] UN 157 Automated Lane Keeping Systems (ALKS)
[34] ISO 22737 Standard for Low-Speed Autonomous Driving (LSAD) systems. (L4)
[35] ERTRAC, SRIA Connected Cooperative and Automated Mobility, 2022
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Cheli F., Fossati, A. &, Mastinu, G. (2021). Enhanced Immersive Reality through Cable-driven Simulators.
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7. Time schedule of the research activities (GANTT CHART)

Milestone 1 Car and driver model ready

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6	BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6
T1.1 Reference models definition	MASTINU G	X	X	X									
T1.2 Data measurement (tyre, mass properties …)	MASTINU G	X											
T1.3 Control models	MASTINU G	X											
T1.4 Driver model selection	MASTINU G	X											
T1.5 Tests on track for model validation and stability asessments	MASTINU G	X											
T1.6 Tests at the driving													

simulator	MASTINU G	X	X	X									

Milestone 2 Bifurcation analysis performed

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**	**BIM. 1**	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**
T2.1 Bifurcation analysis	MASTINU G			X	X	X	X	X					
T2.2. Tassonomy of bifurcations	MASTINU G						X	X					
T2.3 Lyapunof function investigation	MASTINU G	X	X	X	X	X	X	X					
T2.4 Path tracking for motorsport and road vehicles	GUIGGIANI M			X	X	X	X	X					
T2.5 Handover manoeuvre	MASTINU G						X	X					
T2.6 Tests at the driving simulator	MASTINU G				X	X	X	X					

Milestone 3 Stable path tracking for motorsport or road vehicles performed

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**	**BIM. 1**	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**
T3.1 Meetings with Public bodies or Regulating bodies (JRC, ISO committee	MASTINU G							X	X	X	X	X	

Milestone 4 Input for UNECE standard, ISO ready, brief course for governmental staff

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**	**BIM. 1**	**BIM. 2**	**BIM. 3**	**BIM. 4**	**BIM. 5**	**BIM. 6**
T3.2 Derivation of preliminary proposal for	MASTINU												

including correct stability concepts into standards (UNECE 157, ISO 8855)	G										X	X	X
T3.3 Brief course on vehicle dynamics to governmental staff	MASTINU G												X

8. Time schedule of the expenses

nº	Research Units	Expenses	I year						II year					
			BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6	BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6
1.	MASTINU Gianpiero	item A1	X	X	X	X	X	X	X	X	X	X	X	X
2.	MASTINU Gianpiero	item A2												
3.	MASTINU Gianpiero	item B												
4.	MASTINU Gianpiero	item C	X	X	X	X	X	X	X	X	X	X	X	X
5.	MASTINU Gianpiero	item D												
6.	MASTINU Gianpiero	item E												
7.	MASTINU Gianpiero	item F												
8.	GUIGGIANI Massimo	item A1		X	X	X	X	X	X					
9.	GUIGGIANI Massimo	item A2												
10.	GUIGGIANI Massimo	item B												
11.	GUIGGIANI Massimo	item C												
12.	GUIGGIANI Massimo	item D												
13.	GUIGGIANI Massimo	item E												
14.	GUIGGIANI Massimo	item F												

B.2

1. Scientific Curriculum of the Principal Investigator

- Researcher unique identifier: ORCID Id	0000-0001-5601-9059
- URL for web site:	www.polimi.it
Academic age (years from the beginning of scientific activity, i.e. years from first publication or from the beginning of PhD or Medical Specialisation School)	37
Previous positions	Appointed as Full professor TU Delft, 2001 Deputy Director, Production Dep., Stabilimento Militare Pirotecnico dell'Esercito, Capua, 1985-1986
Prizes and awards	A1. Best paper award, IAVSD Symposium, Copenhagen, 2001 A2. Best Presentation Award at the 18th IAVSD Symposium, Atsugi, Aug. 2003: Pennati, M., Gobbi, M., Mastinu, G. “A Dummy for measuring the ride comfort of vehicles” A3. Best Paper Award at the IMECE2003-43005 - ASME Int. Mech. Eng. Congress, Washington, D.C., USA, Nov. 15-21, 2003: Gobbi, M., Mastinu, G., Caudano, M., “Stochastic multi-objective optimisation of a gearbox synchroniser and selector mechanism” A4. Best Paper Award at the ASME IMECE 2004, Anaheim, California, USA Nov.13-19, 2004: F. Levi, M. Gobbi, G. Mastinu, M. Farina, “Multi-objective design and selection of one single optimal solution” A5. Best Paper Award at ASME IDETC 2008 A6. Best Paper Award at ASME AVT Best Paper Award 2011 A7. Best Paper Award at ASME AVT Best Paper Award 2012 A8. Best Paper award SAWE A9. Rocca Fellowship, Massachusset Institute of Technology (MIT): J. Botero February-August 2006. A10. G. Ma...
Visiting academic positions	DLR Oberpfaffenhofen, 1989
Teaching activities and PhD supervision	Co-director and teacher - Master Course "Vehicle Engineering" (in cooperation with University of Modena and Reggio) 1994-2017 Coordinator and teacher of the course "Advances in the Optimal Design of Mechanical Systems" (organized by 'C.I.S.M.' Centro Internazionale di Scienze Meccaniche, Udine, for "European Union-India Cross Cultural Programme") - Birla Science Centre, Hyderabad, India, 22-26 marzo 1999. Coordinator of the doctoral course on Mechanical Engineering, Politecnico di Milano (2001-2005) Deputy director of the doctoral school of Politecnico di Milano (2001-2005) President of the Course on Mechanical Engineering of Politecnico di Milano (Piacenza) 2006-2007 Supervisor of tens of PhD researchers
Other work experience (e.g.	Consultant of Toyota, Peugeot, Citroen, BMW, Porsche, Audi, Daimler, Ford, Pirelli, Iveco,

consultancy if any)	Evobus, Samedeutz-fahr; Danisi, Ambrosetti, Eurolites, Esselunga, ACI Consultant of Courts in Milan and in Varese Founder of the spin-off SmartMechanical_Company (2010). The spin-off works -or has worked- for Brembo, Bridgestone, Space-electronics, Toyota, and major MotoGP teams (it holds 100% of the world market of smart wheels for MotoGP). Consultant of the European Commission on Future Mobility (2020) Cosultant of Regione Toscana, of Regione Piemonte, of Regione Sardegna (review of cluster or research projects)
- Administrative role and position responsibility	Full Professor of Ground Vehicle Engineering Responsible at the Politecnico di Milano of >>Driving Simulator Laboratory (www.drismi.polimi.it) >>Laboratory for Lightweight Construction and Durability Performance (www.lidup.polimi.it) >>Laboratory for the Safety of Transport - Active Safety Division https://www.mecc.polimi.it/ricerca/laboratori-dipartimentali) Secretary General of the Lombardy Mobility Cluster (since 2009) (www.clusterlombardomobilita.it) Head of the Scientific Board of the National Cluster of Sustainable Mobility (since 2014) (www.clustertrasporti.it) Formerly: member of the Scientific Board of the Dep. of Mechanical Engineering
- Scientific organisations/Coordination of academic activities	Founder, at the Politecnico di Milano of >>Driving Simulator Laboratory (2020) (www.drismi.polimi.it) Co-founder, at the Politecnico di Milano of >>Laboratory for Lightweight Construction and Durability Performance (2017) (www.lidup.polimi.it) >>Laboratory for the Safety of Transport of Politecnico di Milano (2000) https://www.mecc.polimi.it/ricerca/laboratori-dipartimentali) Responsible of the Shell-eco marathon team, Politecnico di Milano (student team focusing on electric vehicle motorsport) Responsible of the following EU (or National/Regional) projects AI@EDGE (Partner) ITS Italy 2020 (PI) INPROVES (PI) SOLE2 (PI) SOLE (PI) Superlight Truck Wheels (Partner) DYScarf (Partner) GreenFun (PI) ADEPT (partner) InTenso (PI) Responsible of R&D Contracts at the Dep. of Mechanical Enginering of the Politecnico di Milano with: Ferrari (since 1988), Ferrari F1, Alfa Romeo F1, STMicroelectronics, Comer, Brembo, Honda, Toyota, Pirelli, Samedeutz-fahr, IDIADA, Streparava, ITT, Porsche, Elasis, Stellantis, Fontana Pietro, Lamborghini, Daico, Metelli, Marelli, Sabelt, Mako-shark, Elasis, Fiat Research Center, FAR-ITA, VI-Grade, Gavazzi, Maserati, Pagani Automobili, Space electronics, SmartMechanical_Company, DSP, Invitalia, Ministry of Infrastructure and Sustainable Mobility Resposible of MoLAS project, within "Dipartimenti di Eccellenza", MUR - 2018-2022

	Responsible of Task 2.5.2 of Spoke 13 - National Center of Sustainable Mobility (vehicle electrification) President of the XIX IAVSD Symposium (2005), Milan Italy President of the AVEC24 Conference, Milan Organizer of Vehicle Dynamics Session within SAE WCX (since 2008 to date)
Editorial activity	Associate Editor of the Int. Jou. of Vehicle Dynamics and NVH (SAE) Formerly Associate Editor of Meccanica Member of the Editorial Board of Vehicle System Dynamics Member of the Editorial Board of Vehicles Reviewer of Vehicle System Dynamics Meccanica IMECHE Part D Nonlinear Dynamics Measurement Mechanical Systems and Signals Processing and many other scientific journals
Membership of scientific societies	Member of SAE - Society of Automotive Engineers Member of IAVSD - Int. Association of Vehicle System Dynamics Fellow of SAWE (Society of Allied Weight Engineers) Member of the Board of AVEC (Advanced Vehicle Controls), Japan Member of the Italian Association of Railway Engineers (since 1984 to date)
Funding (current and past)	

Anno	Project title	Person months	Funding organisation
2020	AI@EDGE	500	EU HORIZON 2020 - RIA
2014	ADEPT	324	EU FP7 - MSCA
2012	ITS ITALY 2020	1379	MIUR

Significant career breaks	-
- H-Index (in Scopus):	25
- Total number of publications in peer-reviewed journals	89
- Total IF	9
- n. and total IF of publications where the candidate is first author or equivalent (for the disciplines where the position in the list of authors correspond to the role in the work presented)	4
- N. and total IF of the publications where the candidate is last or corresponding author (for the disciplines where the position in the list of authors correspond to the role in the work presented)	5

2. Scientific Curriculum of the associated PIs

1. GUIGGIANI Massimo

- Researcher unique identifier: ORCID Id	0000-0002-8818-9199
- URL for web site:	http://docenti.ing.unipi.it/guiggiani-m/index.html
Academic age (years from the beginning of scientific activity, i.e. years from first publication or from the beginning of PhD or Medical Specialisation School)	39
Previous positions	Associate professor, Università di Siena, 1992-2000 Assistant professor, Università di Pisa, 1983-1992
Prizes and awards	2019 Textbook Excellence Award (TAA)
Visiting academic positions	Ecole Polytechnique (Paris), Iowa State University (Ames), Instituto Superior Tecnico (Lisbon), University of Stuttgart, Teesside Polytechnic.
Teaching activities and PhD supervision	Vehicle Dynamics, Applied Mechanics, Computer Aided Geometric Design, Numerical Calculus.
Other work experience (e.g. consultancy if any)	Ferrari, Piaggio, Avio, Ohio State University, Apple, Bridgestone, Electricite de France, Siemens.
- Administrative role and position responsibility	President of the MSc Degree in Automotive Engineering, Università di Pisa, 2007-2011
- Scientific organisations/Coordination of academic activities	None
Editorial activity	Associate Editor of: Engineering Analysis with Boundary Elements Mechanism and Machine Theory
Membership of scientific societies	AIMETA IFToMM

Funding (current and past)

Anno	Project title	Person months	Funding organisation
2017	Handling Stability Index	4	Ferrari F1
2015	SPATIAL INVOLUTE GEARS	24	General Electric Avio
2011	Robust Multi-objective Micro-geometry Optimization of Helical Gears	12	Ohio State University

Significant career breaks	None
- H-Index (in Scopus):	23
- Total number of publications in peer-reviewed journals	43

- Total IF	46.30
- n. and total IF of publications where the candidate is first author or equivalent (for the disciplines where the position in the list of authors correspond to the role in the work presented)	16 papers, total IF = 79.13
- N. and total IF of the publications where the candidate is last or corresponding author (for the disciplines where the position in the list of authors correspond to the role in the work presented)	29 papers, total IF = 29.24

3. Main Principal Investigator's scientific publications (Max. 20)

1. BRUNI, STEFANO, MASTINU, GIANPIERO (2005). VEHICLE SYSTEM DYNAMICS - STATE OF THE ART PAPERS OF THE XIX IAVSD SYMPOSIUM. In: SPECIAL ISSUE. - **Altro**
2. Cheli F., Fossati, A. &, Mastinu, G. (2021). Enhanced Immersive Reality through Cable-driven Simulators. ATZ. AUTOMOBILTECHNISCHE ZEITSCHRIFT, vol. 123, p. 58-61, ISSN: 0001-2785, doi: 10.1007/s38311-021-0703-9 - **Articolo in rivista**
3. Comolli F., Gobbi M., Mastinu G. (2020). Study on the driver/steering wheel interaction in emergency situations. APPLIED SCIENCES, vol. 10, p. 1-12, ISSN: 2076-3417, doi: 10.3390/app10207055 - **Articolo in rivista**
4. Mastinu G., Biggio D., Della Rossa F., Fainello M. (2020). Straight running stability of automobiles: experiments with a driving simulator. NONLINEAR DYNAMICS, vol. 99, p. 2801-2818, ISSN: 0924-090X, doi: 10.1007/s11071-019-05438-z - **Articolo in rivista**
5. Gobbi M., Comolli F., Hada M., Mastinu G. (2019). An instrumented steering wheel for driver model development. MECHATRONICS, vol. 64, p. 1-15, ISSN: 0957-4158, doi: 10.1016/j.mechatronics.2019.102285 - **Articolo in rivista**
6. Mastinu G., Lattuada A., Matrascia G. (2019). Straight-ahead running of road vehicles–analytical formulae including full tyre characteristics. VEHICLE SYSTEM DYNAMICS, vol. 57, p. 1745-1774, ISSN: 0042-3114, doi: 10.1080/00423114.2018.1551555 - **Articolo in rivista**
7. Della Rossa, Fabio, Mastinu, Gianpiero (2018). Straight ahead running of a nonlinear car and driver model – new nonlinear behaviours highlighted. VEHICLE SYSTEM DYNAMICS, vol. 1, p. 1-16, ISSN: 0042-3114, doi: 10.1080/00423114.2017.1422526 - **Articolo in rivista**
8. DELLA ROSSA, FABIO, MASTINU, GIANPIERO (2017). Analysis of the lateral dynamics of a vehicle and driver model running straight ahead. NONLINEAR DYNAMICS, vol. 1, p. 1-10, ISSN: 0924-090X, doi: 10.1007/s11071-017-3478-1 - **Articolo in rivista**
9. MASTINU, GIANPIERO, DELLA ROSSA, FABIO, GOBBI, MASSIMILIANO, PREVIATI, GIORGIO (2017). Bifurcation Analysis of a Car Model Running on an Even Surface - A Fundamental Study for Addressing Automomous Vehicle Dynamics. SAE INTERNATIONAL JOURNAL OF VEHICLE NOISE AND VIBRATION, vol. 1, p. 1-12, ISSN: 2380-2170, doi: 10.4271/2017-01-1589 - **Articolo in rivista**
10. Edelmann, Johannes, Ploechl, Manfred, GOBBI, MASSIMILIANO, MASTINU, GIANPIERO, PREVIATI, GIORGIO (2015). Friction Estimation at Tire-Ground Contact. SAE INTERNATIONAL JOURNAL OF COMMERCIAL VEHICLES, vol. 8, p. 182-188, ISSN: 1946-391X, doi: 10.4271/2015-01-1594 - **Articolo in rivista**
11. DELLA ROSSA, FABIO, GOBBI, MASSIMILIANO, MASTINU, GIANPIERO, PICCARDI, CARLO, PREVIATI, GIORGIO (2014). Bifurcation analysis of a car and driver model. VEHICLE SYSTEM DYNAMICS, vol. 52, p. 142-156,

ISSN: 0042-3114, doi: 10.1080/00423114.2014.886709 - **Articolo in rivista**

12. DELLA ROSSA, FABIO, MASTINU, GIANPIERO, PICCARDI, CARLO (2012). Bifurcation analysis of an automobile model negotiating a curve. VEHICLE SYSTEM DYNAMICS, vol. 50, p. 1539-1562, ISSN: 0042-3114, doi: 10.1080/00423114.2012.679621 - **Articolo in rivista**
13. Gagliano C., GOBBI, MASSIMILIANO, MASTINU, GIANPIERO, Pennati M. (2012). Indoor/Outdoor Testing of a Passenger Car Suspension for Vibration and Harshness Analysis. SAE INTERNATIONAL JOURNAL OF PASSENGER CARS - MECHANICAL SYSTEMS, vol. 5, p. 937-948, ISSN: 1946-3995, doi: 10.4271/2012-01-0765. - **Articolo in rivista**
14. G. Mastinu, M. Gobbi, F. Ballo (2021). Hub carrier comprising force and/or moment sensors. PCT/EP2021/053120, Politecnico di Milano - **Brevetto**
15. MASTINU, GIANPIERO, M. PLOECHL (a cura di) (2013). Road and Off-road Vehicle System Dynamics Handbook. Boca Raton, London, New York:CRC PRESS, ISBN: 9780849333224 - **Curatela**
16. F. Ballo, M. Gobbi, G. Mastinu, G. Previati (2021). Optimal Lightweight Construction Principles. Springer, ISBN: 978-3-030-60835-4, doi: 10.1007/978-3-030-60835-4 - **Monografia o trattato scientifico**
17. alessandro lattuada, gianpiero mastinu, giuseppe matrascia (2020). Straight motion of road vehicles. WARRENDALE PA:SAE International, ISBN: 978-1-4686-0129-9 - **Monografia o trattato scientifico**
18. PREVIATI, GIORGIO, GOBBI, MASSIMILIANO, MASTINU, GIANPIERO (2018). MOMENTS OF INERTIA AND PRODUCTS OF INERTIA OF A RIGID BODY - Design principles of measurement systems. Society of Allied Weight Engineers, Los Angeles, CA, USA, ISBN: 9780998329604 - **Monografia o trattato scientifico**
19. MASTINU, GIANPIERO, GOBBI, MASSIMILIANO, C. Miano (2006). Optimal Design of Complex Mechanical Systems with Applications to Vehicle Engineering. p. 1-359, HEIDELBERG:Springer Verlag, ISBN: 9783540343547 - **Monografia o trattato scientifico**
20. BRUNI, STEFANO, MASTINU, GIANPIERO (2005). 19th IAVSD Symposium – Poster Papers. vol. 1, MILANO:Politecnico di Milano, ISBN: 9788890191626 - **Monografia o trattato scientifico**

4. Main scientific publications of the associated PIs (Max. 20, for each associated PI)

1. **GUIGGIANI Massimo**

    1. Gabiccini, M, Bartali, L, Guiggiani, M (2021). Analysis of driving styles of a GP2 car via minimum lap-time direct trajectory optimization. MULTIBODY SYSTEM DYNAMICS, vol. 53, p. 85-113, ISSN: 1384-5640, doi: 10.1007/s11044-021-09789-7 - **Articolo in rivista**
    2. marco gabiccini, lorenzo bartali, massimo guiggiani (2021). Analysis of driving styles of a GP2 car via minimum lap-time direct trajectory optimization. MULTIBODY SYSTEM DYNAMICS, vol. 53, p. 85-113, ISSN: 1384-5640, doi: 10.1007/s11044-021-09789-7 - **Articolo in rivista**
    3. BARTOLOZZI, RICCARDO, FRENDO, FRANCESCO, GUIGGIANI, MASSIMO, Di Tanna O. (2009). Comparison between experimental and numerical handling tests for a three wheeled motorcycle. SAE INTERNATIONAL JOURNAL OF ENGINES, vol. 1, p. 1389-1395, ISSN: 1946-3936 - **Articolo in rivista**
    4. SPONZIELLO, ANTONIO, FRENDO, FRANCESCO, GUIGGIANI, MASSIMO (2009). Stability analysis of a three-wheeled motorcycle. SAE INTERNATIONAL JOURNAL OF ENGINES, vol. 1, p. 1396-1404, ISSN: 1946-3936 - **Articolo in rivista**
    5. FRENDO, FRANCESCO, Greco G., GUIGGIANI, MASSIMO, SPONZIELLO, ANTONIO (2008). Evaluation of the vehicle handling performances by a new approach. VEHICLE SYSTEM DYNAMICS, vol. 46, p. 857-868, ISSN: 0042-3114, doi: 10.1080/00423110802037115 - **Articolo in rivista**
    6. FRENDO, FRANCESCO, Greco G, GUIGGIANI, MASSIMO, SPONZIELLO, ANTONIO (2007). The handling surface: a new perspective in vehicle dynamics. VEHICLE SYSTEM DYNAMICS, vol. 45, p. 1001-1016, ISSN: 0042-3114, doi: 10.1080/00423110601164888 - **Articolo in rivista**
    7. FRENDO, FRANCESCO, GUIGGIANI, MASSIMO, SISI A., DI PIAZZA S. (2006). Analysis of motorcycle models for the evaluation of the handling performances. VEHICLE SYSTEM DYNAMICS, vol. 44, p. 181-191, ISSN: 0042-3114, doi: 10.1080/00423110600869974 - **Articolo in rivista**

8. AMATO T., FRENDO, FRANCESCO, GUIGGIANI, MASSIMO (2002). Handling behaviour of racing karts. SAE TRANSACTIONS - JOURNAL OF PASSENGER CARS: MECHANICAL SYSTEMS, vol. 1, doi: 10.4271/2002-01-2179 - **Articolo in rivista**
9. T. Amato, FRENDO, FRANCESCO, GUIGGIANI, MASSIMO (2004). Handling behaviour of vehicles with locked differential systems. In: FISITA 2004 World Automotive Congress. vol. CD-F2004I036, p. 267-281, Barcelona, Spain1, 23-27 Maggio 2004 - **Contributo in Atti di convegno**
10. Guiggiani M. (2018). The Science of Vehicle Dynamics: Handling, Braking, and Ride of Road and Race Cars. p. 1-550, Springer International Publishing, ISBN: 978-3-319-73219-0, doi: 10.1007/978-3-319-73220-6 - **Monografia o trattato scientifico**
11. GUIGGIANI, MASSIMO (2014). The science of vehicle dynamics. Dordrecht:Springer, ISBN: 9789401785327, doi: 10.1007/978-94-017-8533-7 - **Monografia o trattato scientifico**
12. GUIGGIANI, MASSIMO, M. (1998). Dinamica del veicolo. p. 1-380, TORINO:CittàStudiEdizioni, ISBN: 9788825173000 - **Monografia o trattato scientifico**

5. Main staff involved (max 10 professors/researchers for each research unit, in addition to the PI or associated PIs), highlighting the expected time commitment

List of the Research Units

Unit 1 - MASTINU Gianpiero

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	MASTINU Gianpiero	Professore Ordinario	Politecnico di MILANO	gianpiero.mastinu@polimi.it (adesione completata il 14/11/2022)	4,0
2.	PANZANI Giulio	Professore Associato (L. 240/10)	Politecnico di MILANO	giulio.panzani@polimi.it (adesione completata il 24/11/2022)	5,0
3.	PREVIATI Giorgio	Professore Associato (L. 240/10)	Politecnico di MILANO	giorgio.previati@polimi.it (adesione completata il 13/11/2022)	6,0
4.	GOBBI Massimiliano	Professore Ordinario (L. 240/10)	Politecnico di MILANO	massimiliano.gobbi@polimi.it (adesione completata il 12/11/2022)	6,0
5.	DERCOLE Fabio	Professore Associato (L. 240/10)	Politecnico di MILANO	fabio.dercole@polimi.it (adesione completata il 20/11/2022)	5,0
6.	COLOMBO Alessandro	Professore Associato (L. 240/10)	Politecnico di MILANO	alessandro.colombo@polimi.it (adesione completata il 14/11/2022)	5,0
7.	DELLA ROSSA Fabio	Ricercatore a t.d. - t.pieno (art. 24 c.3-b L. 240/10) (*data fine contratto: 16/01/2025*)	Politecnico di MILANO	fabio.dellarossa@polimi.it (adesione completata il 23/11/2022)	9,0

Information on the new contracts for personnel to be specifically recruited

Number of expected research contracts	Number of expected PhD scholarships	Overall expected time commitment (months)
0	0	32

Unit 2 - GUIGGIANI Massimo

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	GUIGGIANI Massimo	Professore Ordinario	Università di PISA	massimo.guiggiani@unipi.it (adesione completata il 24/11/2022)	4,0
2.	GABICCINI Marco	Professore Associato (L. 240/10)	Università di PISA	m.gabiccini@ing.unipi.it (adesione completata il 24/11/2022)	5,0

Information on the new contracts for personnel to be specifically recruited

Number of expected research contracts	Number of expected PhD scholarships	Overall expected time commitment (months)
0	0	11

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6. Information on the new contracts for personnel to be specifically recruited

nº	Associated or principal investigator	Number of expected research contracts	Number of expected PhD scholarships	Overall expected time commitment (months)
1.	MASTINU Gianpiero	0	0	32
2.	GUIGGIANI Massimo	0	0	11
	Total	**0**	**0**	**43**

7. PI “Do No Significant Harm (DNSH)” declaration, in compliance with article n. 17, EU Regulation 852/2020. (upload PDF)

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MUR also has the right to the dissemination of the main economic and scientific data related to the funded projects.”.

Date	*(inserted by system at the closing of the application)*