Leveraging Transdisciplinary Engineering in a Changing and Connected World
P. Koomsap et al. (Eds.)

doi:10.3233/ATDE230612

Transdisciplinary Setup Guide for Automated Maintenance Training Generation in Virtual Reality from Virtual Commissioning

Sascha QUAST[1] and Kathrin KONKOL
Fraunhofer Institute for Production Systems and Design Technology IPK, Department Extended Reality, Berlin, Germany

Abstract. In automated production industries, qualified maintenance is important. Planning and executing complex practical maintenance training scenarios on real machines can be expensive. To reduce cost, virtual training simulations in Virtual Reality (VR) are slowly being established in the virtual commissioning sector, but implementation times can be long and costly when each new training scenario needs to be implemented manually. This paper describes the outcome of a three-year research project, which addressed an automated generation of gamified maintenance training in VR based on existing virtual commissioning scenarios instead of manually configuring the machine logic on an example in the automotive industry. With the project partners from the automotive and gaming industry, a demonstrator was created. The result is a transdisciplinary setup guide for three different user types: the commissioner, the trainer, and the trainee. The users are supported with a combination of automated functions and included descriptions to utilize VR without being VR experts. The first user, the commissioner, can generate a VR scene from virtual commissioning and connects them so that the real machine behavior of the virtual Programmable Logic Controller (PLC) and Numerical Control (NC) can be used in VR over the virtual Human Machine Interfaces (HMI) like touchscreens, buttons, and other machine parts. The trainer can configure training in this virtual commissioning scene for the maintenance trainee to use for virtual machine training. The demonstrator received positive feedback from key users of the automotive industry and should be tested for their training in the next steps.

Keywords. Virtual reality, maintenance training, transdisciplinary setup guide, virtual commissioning, OPCUA, digital manufacturing simulation, integrated automation, robot simulation

Introduction

The need for qualified maintenance in automated production industries is crucial to ensure efficient and safe operations. However, providing hands-on training on real machines can be expensive and time-consuming, as the production line needs to be stopped during the time of the training. One alternative solution is to build a machine, especially for training that has similar functions to the real machine. The development,

[1] Corresponding Author, Mail: sascha.quast@ipk.fraunhofer.de.

construction, and operating costs for training centers can be high because of the additional personnel costs, equipment, and space required [1].

A third option is to create a copy of the real machine in VR. The integration of VR technology in industrial training has gained significant attention in recent years. It offers a safe and cost-effective alternative to traditional training methods by providing a realistic simulation of the real-world environment [2]. It promotes intuitive learning and gains acceptance among trainees [3]. However, the process of creating a VR training scenario from scratch is time-consuming and expensive [2]. A lot of data, like the geometries and the kinematics of the machine, must be prepared and implemented. Furthermore, the machine logic for each training scenario should be created manually as realistically as possible. To have a realistic training scenario, the virtual environment needs to offer interaction possibilities and space for errors, which the trainee needs to learn how to avoid them. Therefore, the training environment does not only need functionality for the correct execution of the training scenario but also some possible incorrect solution functionality. In addition, all future changes to the machine need to be adopted in the training environment which claims large setup times that relate to high costs.

The use of VR for maintenance training itself apart from the expensive setup has several benefits. With Storytelling and Gamification aspects like hints, personnel costs can be reduced, because the trainer doesn´t need to guide the trainee through the scenario by himself [4]. In addition to increasing trainees' motivation, the training itself can also be made more efficient [5]. The training scenario can also be transported to different locations, such as different facilities, or used while working from home, as only a VR Head Mounted Display (HMD) and laptop are required.

To use the benefits of VR without the negative aspect of a high setup time we conducted a three-year research project, which was described in [6], that aimed at developing a fast creation of gamified maintenance training in VR based on existing virtual commissioning scenarios. We collaborated with project partners from the automotive industry and gaming to develop a demonstrator that utilizes automated functions by generalizing the machine parts and training to enable the user to utilize VR without being an expert in VR technology.

During the project, we recognized that the team of different disciplines could benefit from a transdisciplinary VR setup guide to reduce the complexity around the VR maintenance training of the highly automated production machines. VR is already used for communication across disciplines by viewing the design in the same VR environment [7], but neither concentrated on collaboration during the VR setup nor with disciplinary-specific filters. We wanted to enable each discipline to concentrate on its technical expertise for more efficient collaboration to reduce the setup time of the VR scene. Each user should have his layer which only shows functions and instructions that are important to him while being able to test the whole scene to see the overall picture enabling the team members to be a niche experts and understand the whole project [8] mentioned as the main paradox in his conclusion. In combination with the developed automation functions from the research project, the commissioner could concentrate on the virtual commissioning preparation, the trainer on the training preparation, the trainee on learning the maintenance, and the VR expert on the working environment. This setup guide could be adopted for a variety of machines and possible future adoptions.

This paper describes the design and implementation of the automatic functions and the extension of this with an interdisciplinary Setup Guide, which enables transdisciplinary collaboration within this maintenance training scenario. In the first section of this paper, the realization and the results are described. The last sections, the discussion, and the conclusion display the relevance and possible next steps.

1. Realization

The goal of the research project was to create a demonstrator that shows the possibility to generate a Training scenario in Virtual Reality from the data of a virtual commissioning scene in Siemens Process Simulate like [6] described it. Therefore, the following individual technologies should be developed: The application kit, the automatic setup functions, gamification and storytelling, and a virtual commissioning scene as examples.

The application kit defines the infrastructure of the automatic VR scene generation. It includes defining the data required to build a VR scene and how to use the existing data of the virtual commissioning scene for it, as well as additional data prepared for the training functionalities like a brush to clean the sensor. The data includes the geometries of the machine, the production facility, and the tools as well as the positioning of those geometries and the relation of the positioning. In addition, the kinematics of the machine and production facility, like robot axes and doors, but also button behaviors are needed. For real machine behavior, the signals of the machine, like proximity sensors, button signals, and axis values, but also light as feedback for the user is necessary. To connect the data, a hierarchy and the relation of all these data internally and among each other should be clear. For a seamless export and import the data type should be defined as well as the connection between the VR scene and the virtual commissioning.

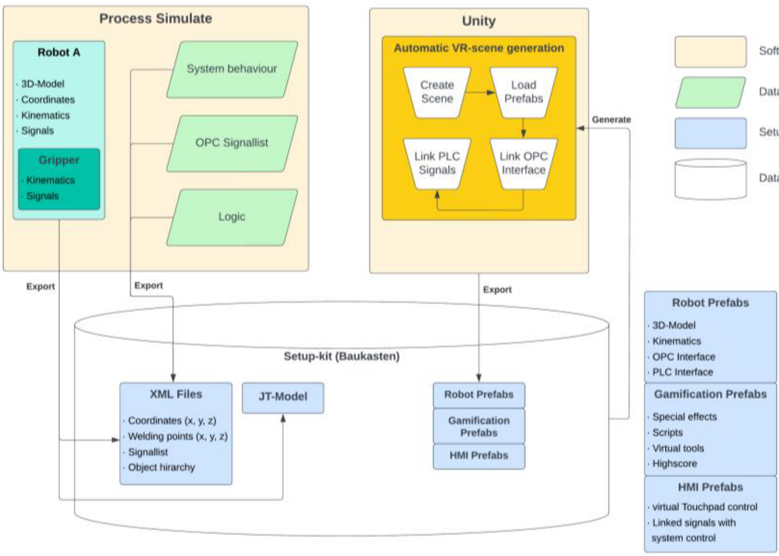

Figure 1. The architecture of an application kit.

Figure 1 demonstrates the concept of infrastructure. The aim was to create a generic structure that would enable the automatic VR scene creation in Unity of the correct data from Process Simulate by using the “Baukasten” (Figure 1) as a handling tool. The second part was to develop functions for the automated VR training scene generation with structured data import and an interface to the virtual commissioning scene for real machine behavior. The experienced project partner from gaming integrated gamification and storytelling elements to optimize the user experience. An exemplary virtual commissioning scene was created by the project partner from the automotive industry. Finally, the technologies should be combined in a demonstrator that shows the automatic creation of a VR scene from the exemplary virtual commissioning scene and enables an operator to be trained on a virtual production machine. In addition, exemplary error cases should be created as a task for the maintenance trainee. [6]

1.1. Function List with the naming convention for a generic structure

The Function List specifies the ontology of the machine with its different types of parts. With its naming convention, it enables the automatic transport of the part properties and allocations between the simulation and the VR scene. Thus, we used an integrated export tool for the geometry and a scripted export tool for the metadata that detects the type. These two files with geometry, kinematics, and behavior related to the virtual PLC signals of e.g. different robot axis can be generically imported and connected in the VR scene because the import function identifies the axis type. Other types are e.g. buttons, touchscreens, tools, sensors, or lights which will be integrated differently into the VR scene and prepared with their corresponding behaviors and training prefabs related to their specific type.

1.2. The connection between the virtual commissioning scene and the training in VR

To realize real machine behavior in VR we created a connection between the simulation environment in the virtual commissioning scene and the Virtual Reality scene in Unity. The simulation environment consists of a variety of software that is centered on Process Simulate and uses a virtual programmable logic controller (PLC) and a virtual robot control system (RCS) to simulate the real machine behavior. The OPCUA connection transports the signals like axes values and light signals from the virtual commissioning scene in Process Simulate to the VR scene in Unity and signals like button states in the other direction. A virtual touchscreen in VR mirrors the computer monitor that shows the virtual machine HMI which is connected to the machine simulation. The graphical user interface (GUI) on it can be used like a real touchscreen of the machine to control the real machine. E.g. the trainee can push the GUI button “cycle start” on the virtual touchscreen to run the automation process of the virtual robot in VR.

1.3. Error Creation and Handling

With the real machine behavior in the VR scene and the possibility to interact with it, the trainee was able to use the virtual machine like the real machine without blocking the real machine in the production and without the risk of destroying the machine or hurting himself. He could be trained to operate the working machine. More important for an operator is to solve errors that occur on real machines. Therefore, we developed a function to raise an artificial error on the machine that the trainee should solve. The function in Unity forces a signal in the virtual PLC simulation on a value that simulates a false behavior of the machine. As an example, we forced an end position of a clamp on false that should become true after the clamp reaches the end position to fix the workpiece as is demonstrated in Figure 2.

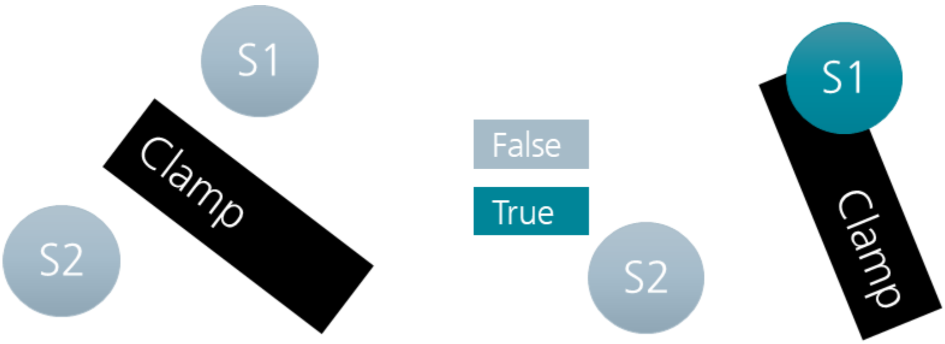

Figure 2. The Error Creation on a clamp.

On the real machine, this false staying signal could occur e.g. because a cable is loose, or broken, or the optical sensor is just dirty. The simulated machine logic in Process Simulate handles this forced signal as an error because it expected the signal to turn true after a maximum amount of time. The consequence is that the machine stops and shows an error message on the HMI touchscreens like it would on the real machine. The operator has to inspect this error message in VR and search for the cause of this error. With the hints of the implemented gamification, he can find the error of e.g. a broken cable and replace it on the virtual machine. The training logic detects this replacement and stops forcing the signal. By closing the safety requirements, quitting the errors on the machine, and restarting it, the trainee can reactive the production of the virtual machine and thus complete the training. Most of these steps the trainee needs to perform are automatically generated, or part of the machine logic, so they don´t need to be implemented manually, like in other existing training in Virtual Reality.

2. Results and Discussion

During the development phase of the VR environment, we determined that there are multiple key users for the training scenario: The virtual commissioner, the trainer, and the trainee. The virtual commissioner is creating and maintaining the simulation environment, the trainer is setting up the training environment from the virtual commissioning scene and the trainee uses the VR environment to use the training. The setup described in the previous chapters is an assembly of complex dependencies and data structures, that all need individual expert knowledge.

We decided to create individual views for each discipline as the user role layer of the application and implemented it as a setup guide that enables transdisciplinary work within one complex VR environment. Each of the roles as commissioner, trainer, or trainee gets the filtered information and interaction possibilities that are necessary for its work.

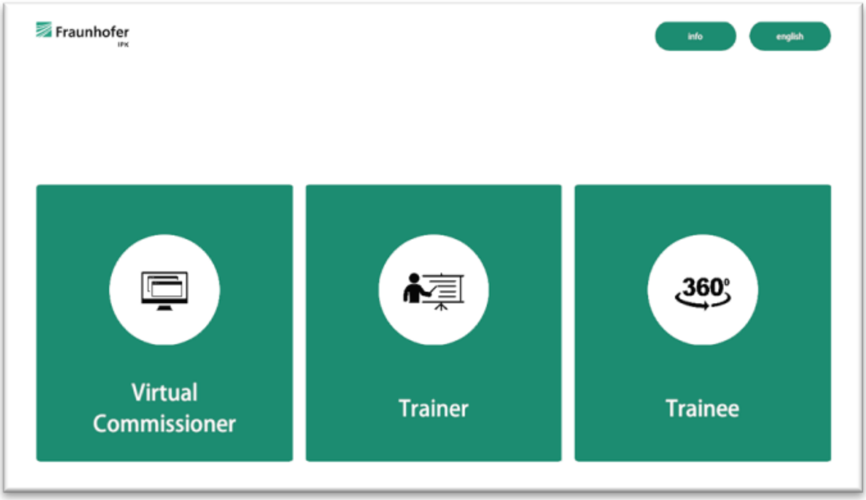

Figure 3. Setup guide - user overview.

Figure 3 shows the main page with the user overview. With this layer, each user has access to the same data but with different visualizations. This enables the collaboration of transdisciplinary project participants while keeping the complexity and knowledge needed to use the application at a low level. The commissioner role and trainer role can update the configuration for new machines, new functions, or new training methods so that so generic VR scene creation can be applied to a wider field of use cases. Instead of manually creating a new Virtual Reality tool, like a machine training in Virtual Reality, they are updating the tool that creates Virtual Reality content to use. Each expert role can add its expert knowledge like the virtual commissioner role can add a new type of machine part and the trainer role can add new hints for this to optimize the experience for the trainee role. The setup guide handles the combination and gives them easy access with a disciplinary-specified filtered user interface.

We implemented this setup guide as a demonstrator that already includes some functions and some functions are visualized as ideas without functionalities. Some of those are shown in the following.

2.1. The Commissioner's view

One role is the virtual commissioner which needs to prepare the VR scene in the first place and connect the simulation to it for real machine behavior. In the main menu, it sees the overview of every machine setting that has been created so far, as shown in Figure 4.

From there it can set up a new VR scene from an existing virtual commissioning scenario. It will be guided through the steps with instructions like a description of which data to prepare for the setup, where to get this data, and how it can export it. Also, it will be shown if the data has some errors and how to correct them by e.g. adopting the naming convention to its virtual commissioning scene so that the data can be exported correctly. It can also make some recommendations to the developers on how to optimize or add the naming convention to simplify the process of creating a VR scene. It can also add machine parts. If a new type of machine part is needed, a software function is provided to request a new type for a machine part that will be added to the naming convention. The virtual commissioner role can also add errors, that occur on the real machine. Typically, it would know about these errors and how to fix them.

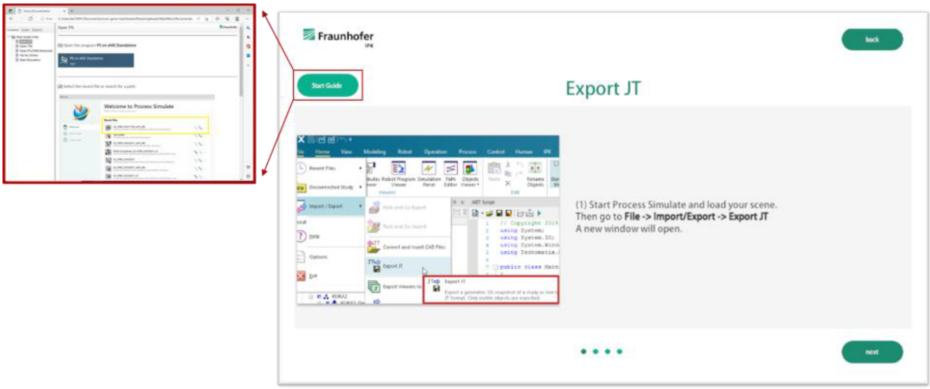

Figure 4. Setup guide – virtual commissioner guide.

2.2. *The Trainer's view*

The trainer role has the same functionality to add new errors to prepare an issue the trainee role needs to solve. The following procedure to solve this error is given by the machine logic that is simulated in the connected virtual Programmable Logic Controller (PLC), so the trainer role does not need to emulate this logic. To guide the trainee role through the scenario, it can create hints, dependent on the current status of the machine and the position of the trainee role, e.g. point out to the screen where the error message appeared. They can also be optional to choose for the trainee role or time-dependent, e.g. a hint to check the sensors if the trainee role lingers too long in front of the HMI panel where the error message appeared. The hints can be a combination of textual descriptions and visualizations. The visualizations can be prepared as basic visualizations, like highlighting an object. All these prepared hints can be configured in an interface that could look like the one in Figure 5.

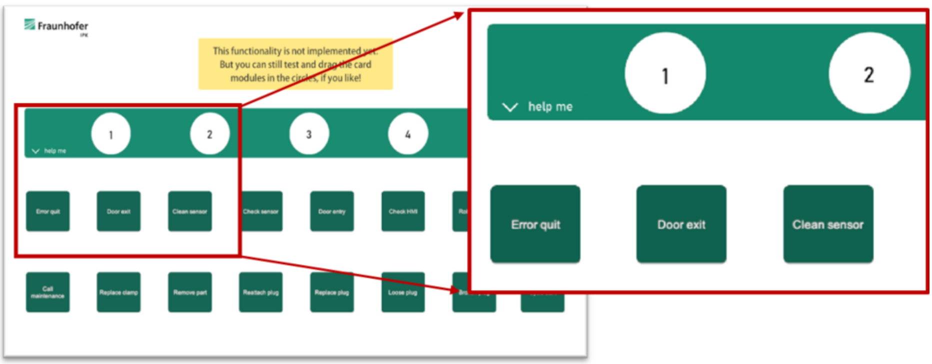

Figure 5. setup guide – training configuration.

In addition, the trainer role can create new visual hints in the VR environment that can be derived to prepare hints and subsequently use them for further training configurations. To test the trainee role's focus, the trainer role can also add distractions in the training configuration, e.g. an unimportant phone call.

To calculate a training score, the trainer role can assign positive and negative points to the training steps. The trainee role could e.g. get negative points if it falls for a distraction, or needed a hint.

Different training modes can be used to separate the beginner trainee role at its first training where all hints are needed and maybe no, or just a few distractions, and the test mode without any hints and many distractions. This affiliation of hints and distractions to the corresponding mode can be configured as a default so that future configurations can be created faster.

2.3. The trainee's view

The trainee role has an overview of different training chosen for it and its progress in these topics. It can start or schedule a new training from there. In addition, it and also the trainer role can view a board with statistics and ranking, shown in Figure 6, to optimize the training progress and experience. Like the virtual commissioner role, the trainee role and trainer role can report errors or suggest optimizations to the developers, to optimize the experience of the VR setup guide.

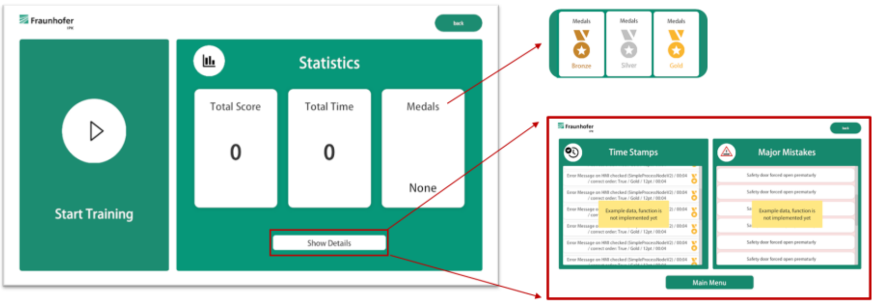

Figure 6. Setup guide – training statistics.

2.4. Discussion

This demonstrator could also serve as a general proposal for VR setup guides, not only for virtual commissioning but also in other areas. During the project, it appeared that the integration of automation into a setup guide with instructions and explanations could lead to a more user-friendly VR application that amplifies efficient usage. Additionally, it connects different disciplines in a team which could lead to better collaboration. Together they could use the application and adapt it to future changes of the machine, or new machines that could prolong the life of the application. An application that can be maintained by the users could remain longer in usage because the users can adapt it for future changes without the need for a developer to work on it.

The combination of a 2D user interface that enables the setup and use of a virtual reality scene also connects the VR experts with the VR beginners, as it lowers the complexity of the application's initial set-up.

The setup guide could be extended for further use cases of VR and also AR to be used by further disciplines. The existing applications to view designs in VR [7] could also be extended with the transdisciplinary VR setup guide to enable users from different disciplines to prepare the content of their technical expertise to discuss it in VR. By having one tool for the handling of VR content with layers for different users, the challenges of VR could be addressed transdisciplinary and leverage the benefits collaboratively.

3. Conclusion

The outcome of the research project is a demonstrator that shows the possibilities to simplify the generation of VR training with real machine behavior. In addition, we developed a setup guide that can bring this new technology to end users to try it in their working environment with a low boundary of needed knowledge.

The next steps should be to gain experience with this setup guide for VR in industrial environments through user testing and get into a discussion with those users. Part of this discussion should be the extendibility of more use cases, more user filters and more interfaces to other software to combine a bigger transdisciplinary field. An interface to PLM is to consider integrating VR into product management. According to that the adaptability of the training and the machine should be increased as well as additional automation to replace instructions step by step. These functions should be visualized to keep the user involved in what happens. The focus should be the goal to optimize team coordination with easy access to VR tools to reduce the project and product costs.

Acknowledgment

SPONSORED BY THE

Federal Ministry of Education and Research

References

[1] S. Webel, U. Bockholt, T. Engelke, M. Peveri, M. Olbrich, C. Preusche, Augmented, Reality Training for Assembly and Maintenance Skills, *BIO Web of Conferences 1*, 2011, p. 97, DOI: /10.1051/bioconf/20110100097

[2] S.K. Renganayagalu, S.C. Mallam and S. Nazir, Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review. Technology, *Knowledge and Learning*, 2021, Vol. 26, pp. 999-1041.

[3] F. Grandi, M. Peruzzini, S. Cavallaro, M. Pellicciari, A training methodology based on virtual reality to promote the learning-by-doing approach, *International Journal of Advanced Operations Management*, 2021, Vol. 13:3, pp. 275-291, doi: 10.1504/IJAOM.2021.120513.

[4] M. Numfu, A. Riel, and F. Noel, Virtual Reality Based Digital Chain for Maintenance Training, *Procedia CIRP*, 2019, Vol. 84, pp. 1069–1074, doi: 10.1016/j.procir.2019.04.268.

[5] F. Palmas, D. Labode, D. A. Plecher, and G. Klinker, Comparison of a Gamified and Non-Gamified Virtual Reality Training Assembly Task, *11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, Vienna, Austria, 2019, pp. 1-8, doi: 10.1109/VS-Games.2019.8864583

[6] C. Masuhr, A. Geiger, K. Konkol, Automatisierte Erstellung von Virtual-Reality-Schulungen: Auf Basis von Modellen und Informationen der virtuellen Inbetriebnahme, *Zeitschrift für wirtschaftlichen Fabrikbetrieb,* 2021, Vol. 116, no. 10, pp. 744-747. https://doi.org/10.1515/zwf-2021-0162.

[7] L.P. Berg, J.M. Vance, Industry use of virtual reality in product design and manufacturing: a survey. *Virtual Reality*, 2017, Vol. 21, 1–17 https://doi.org/10.1007/s10055-016-0293-9.

[8] A. Kharlamov, G. Parry, L. Newnes, When and Where Is Transdisciplinary Engineering Applied in Projects? A Case Study, *Advances in Transdisciplinary Engineering*, 2019, Vol. 10, pp. 12-21, 10.3233/ATDE190102.