Smart Connection Technology Framework – AI-based Creation of Connection Technology Elements

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Abstract. Automotive product development and the manufacture of automotive products are subject to a series of individual development and production steps. One of these production steps is the assembly of the individual components using suitable connection techniques to create the entire BIW (body in white). However, before the appropriate connection processes can be applied, they must be defined in a series of development steps. Each connection technology element must be created (by CAD support), tested (by CAE support) and is subjected to several CAM-related criteria. Which connection technology element is best suited to join two or more components depends on several factors, including the material pairing. This means that CAD engineers must consider a variety of parameters in order to select the appropriate connection technique variant. Considering that modern BIWs require several thousand connection elements to assemble the entire BIW, we are talking about an enormous manual effort. This currently standardized procedure has two main disadvantages. Firstly, an enormous number of resources (time, costs, manpower, etc.) is required to create all the connection technology elements of the BIW in CAD environments. Secondly, the manual creation of several thousand connection technology elements can lead to a relatively high failure rate. For both disadvantages shown, the automatic creation of connection technology elements in CAD environments can be used as a remedy. With the help of AI-based approaches and several available parameters, a suggestion for the CAD engineer should be offered as to which connection technique variant is the most efficient for the given conditions. In a further step, CAE- and CAM-based models, parameters, and values could also be included in this prediction and further increase the efficiency in the process of the automatic creation of connection technology elements.

Keywords: Knowledge-based Design, Process Optimization, Smart Connection Technology, CAx, Automotive Body Development
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1 INTRODUCTION

Due to a rapidly advancing automotive industry characterized by constantly changing boundary conditions and requirements, such as the reduction of local CO_2 emissions in the driving cycle, production processes and facilities as well as automotive development and engineering processes must also be adapted. On the one hand, entire production halls must be converted from the classic combustion engine to electro mobile applications, while on the other hand, advancing digitalization plays a major role, particularly in development and engineering processes.

In addition, automotive suppliers and OEMs are under enormous pressure due to globalization, a highly competitive market and stagnating sales numbers in many major target markets. One way to withstand this pressure and increase competitiveness is to optimize the use of resources and time. Particularly in the development of vehicles or individual vehicle components, there is enormous potential to save resources and time to ensure accelerated development and thus earlier market launch of products.

Another trend in the automotive industry that has already been observed for several years is the use of different materials in the body-in-white (BIW). The so-called multi-material body design combines the advantages of a cost-effective and at the same time weight-saving body structure. In addition to the many advantages of multi-material body design, there is also the increasing complexity of the necessary connection technology elements. While BIW made of different types of steel only uses spot welds and weld seams to join two or more sheets, BIW made of multiple materials (e.g., steel, aluminum, CFRP (carbon fiber-reinforced plastic), magnesium, or other plastics) usually use a variety of connection elements. This diversity means that CAD (Computer-Aided Design) as well as CAE (Computer-Aided Engineering) and CAM (Computer-Aided Manufacturing) engineers have an increased additional workload when developing BIWs [12], [15].

For these reasons, the extended abstract presents a novel approach in the context of an AI-based tool to support development and design processes. The aim of the tool utilized is to support engineers with the help of a large amount of high-quality data and to make a prediction as to which connection element is best suited for the components to be joined. The predictions incorporate knowledge and parameters from CAE and CAM development environments [12].

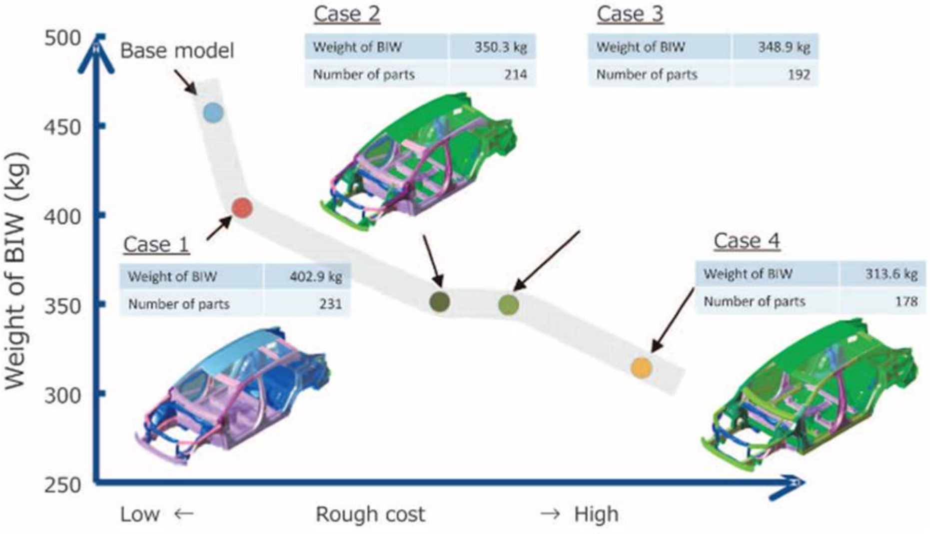
2 STATE-OF-THE-ART

Vehicle bodies today are made from a variety of different materials. From pure steel bodies over aluminum bodies to multi-material bodies, engineers have to make a decision between cost efficiency and optimized weight and safety criteria. However, not only the material itself, but also the connection technology elements play a major role in the design and production of an automotive body. Modern car bodies consist of several thousand, up to 10,000 connection technology elements to assemble the entire body, c.f. [5], [9], [11].

Figure 1 gives an overview of different material combinations in an exemplary automotive BIW in terms of BIW weight, cost, and number of parts. As shown in Figure 1, there are different strategies for manufacturing a BIW. Decades ago, the predominant combination to produce a BIW was a steel-based body joined by various welding disciplines. Today, multi-material BIWs are mostly used in combination with a variety of connection technology elements.

This change to a cost-efficient and even lightweight body combined with optimized safety requirements also has an impact on development and engineering processes. The use of a variety of materials and connection technology elements causes a more complex development of automotive bodies and products. Currently, CAD engineers must decide whether to use element A or element B of the connection technology. Of course, this decision is made with the support and feedback of CAE and CAM engineers; in so-called CAD-CAE, respectively, CAD-CAM optimization loops. However, these CAD-CAE / CAD-CAM optimization loops are very time-consuming and resource-intensive, which slows down the overall development and thus puts the manufacturer at a disadvantage in terms of competitiveness. In addition to the fact that current CAD-CAx optimization loops are very resource-intensive, the fact of data quality and data maturity level must also be taken into account. In addition, the creation and revision of connection technology elements is currently a manual engineering process performed by CAD engineers. Therefore, CAD engineers invest a lot of time, effort and resources in different CAD environments to ensure that the vehicle BIW can be manufactured and meets the simulation requirements.

Since in the automotive development and manufacturing process as many tasks as possible are to be shifted to the early phases (cf. [1], [2], [6], [15]), the selection of a suitable connection technology element depends on the data available at this point of development. For example, the selection of the appropriate material, weight of the components, mechanical dimensions, crash and durability properties, etc. couldn't be available at that stage. Since changes during the project, e.g., the integration of CAD-CAE or CAD-CAM optimization loops results, etc. may occur, the selection of suitable elements of the connection technology in automotive engineering had to be changed several times, which in turn delayed the development.



Case 1

Material constitution	Rate (%)
< TS590 MPa steel	24.1
≧ TS590 MPa steel	32.9
≧ TS780 MPa steel	38.3
Hot stamping steel	3.8
Al Extrusion	0.9

Case 2

Material constitution	Rate (%)	
Steel		50.1
Al Extrusion	12.0	49.9
Al sheet	30.1	
Cast Al	7.8	

Case 3

Material constitution	Rate (%)	
Steel		61.4
Al Extrusion	4.8	38.6
Al sheet	26.2	
Cast Al	7.6	

Case 4

Material constitution	Rate (%)	
Steel		27.5
Al Extrusion	20.5	72.5
Al sheet	37.6	
Cast Al	14.4	

Figure 1: Different material combination in an exemplary automotive BIW in regard to weight and costs, referred to [13].

To overcome the barrier of a cost- and time-inefficient development in terms of selecting the appropriate connection technology the engineers must be supported by tailor-made tools which enhance automotive development and engineering processes [10]. Therefore, the next section introduces a novel approach of a smart connection technology tools (named *SJTT*), which supports engineers with predictions based on high-quality data, to select the appropriate connection technology element combined with an accelerated development.

3 SMART JOINING TECHNOLOGY TOOL (SJTT)

According to [6] and [11], the automotive development process is divided into five sections: "definition", "concept", "pre-development", "series development" and "pre-series & SOP". Figure 2. shows the different stages in logically sequenced order.

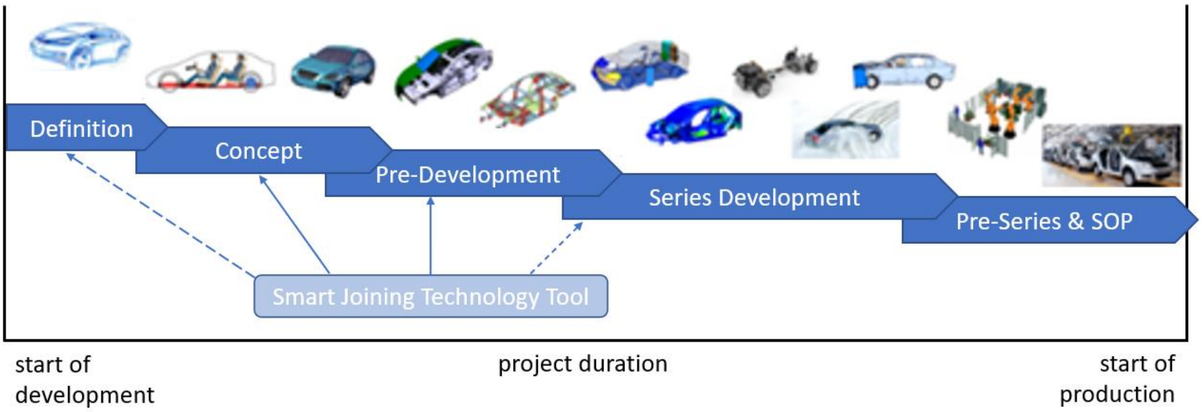


Figure 2: Automotive development process, according to [6] and [11].

Computer-aided disciplines (CAx) play an important role, especially in the early stages, which means that these phases have the highest potential for intervention in development. Beside the phase "definition" in that among other things feasibility studies, technical assessments and cost analyses are carried out, the phases "concept" and "pre-development" are of utmost importance for the creation process of connection technology elements. For this reason, the tool supports the individual development stages in both phases, "concept" and "pre-development", as well as in large parts of the phase "series development".

Figure 3 gives an overview of the systematic workflow of the *SJTT*. As initial input data, the *SJTT* either automatically or manually checks the 3D CAD model. In the "automatic check" mode, the *SJTT* checks all components; in the "manual check" mode, the user must check the components and thus find the coordinates himself. The term "components" refers to all individual parts, such as metal sheets, which are necessary for the production of the BIW. In order to predict a suitable connection technology element, installation space tests are first carried out at the automatically or manually selected coordinates to determine which connection technology elements are suitable from an installation space point of view. Furthermore, the *SJTT* checks automatically how many components (usually between two and five in the automotive industry) need to be joined at the selected coordinates. The components to be joined are then analyzed on the basis of the underlying 3D CAD data. This means that all the necessary data and properties from the 3D CAD model, such as the number of components to be joined, the materials of the components and results from space analyses, are available.

As a next step, the AI-based prediction algorithm in the *SJTT* checks whether further criteria and parameters need to be considered. Several databases (DB) are used for this purpose. On the one hand, high-quality data from CAE and CAM environment databases and on the other hand, image engine databases are available. High quality data is data that has already been obtained from successfully implemented automotive projects. In addition to empirical values, characteristic values from the various CAx environments also play an important role. Furthermore, this data can be applied directly, without having to apply any data preparation (e.g. conversion, transformation into other data formats, change of data structure, etc.) in advance. In addition to empirical and characteristic values, the results of CAD-CAE and CAD-CAM or further CAD-CAx loops also play an essential role.

The CAE and CAM environment databases contain a large amount of data from projects that have already been successfully completed and benchmark databases. These support the AI-engine in the prediction process. Furthermore, this prediction process is supported by a high quantity of images from different sources. An image engine generates high-quality data out of the vast number of images by a developed algorithm. The last decisive point for the prediction is the economic aspects of the respective connection processes, c.f. [4].

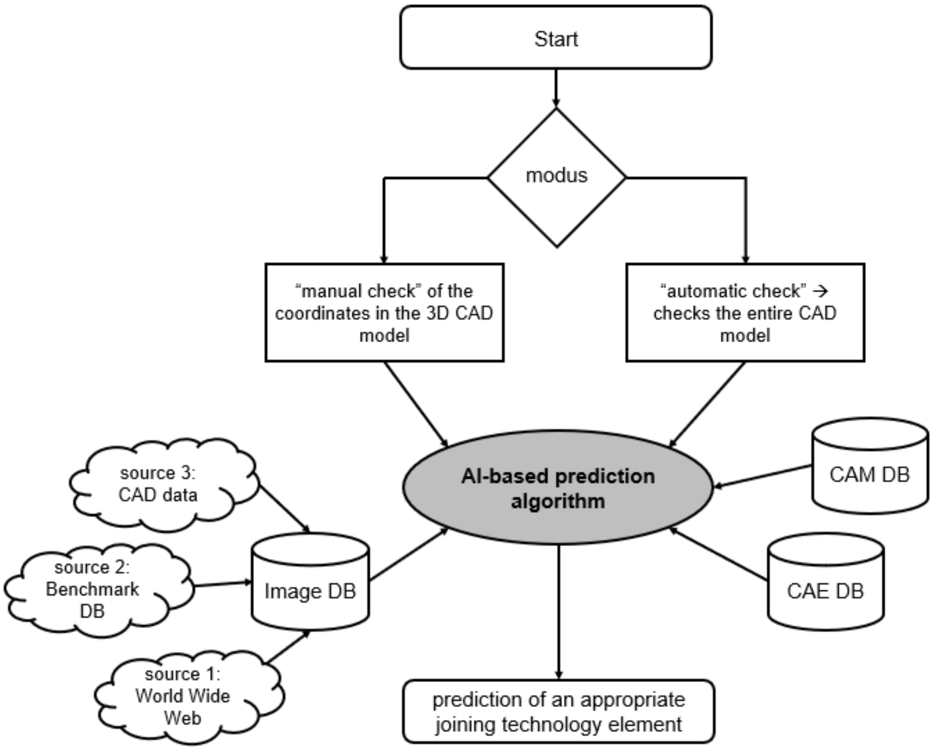


Figure 3: Systematic workflow of the *SJTT*.

The proposed *SJTT* includes a viewer for the CAD models, which deals with neutral data formats, e.g., STEP (Standard for the Exchange of Product Data) files representing the CAD models. The system extracts the CAD data from the CAD model and recognizes its main features. Besides, the system shows the interaction between the CAD model of the BIW components and predicted connection system on the system viewer. The system gained the BIW components materials from predefined files stored in XML (Extensible Markup Language) files. The system based on EWDrew as add-in module to Visual Basic Program interacting with MATLAB Program.

At the end of the *SJTT* workflow, the engineer is provided with a prediction of the most suitable connection technology element, selected based on the available parameters and criteria. These predictions support the engineers and offer an approach to reduce the number or even completely replace CAD-CAE or CAD-CAM optimization loops.

4 AI-BASE PREDICTION ALGORITHM

In the first stage of the *SJTT*, an expert system based on given databases (e.g., databases for materials, connection techniques and images) is used to select the appropriate connection method. An example of the proposed database is shown in Table 1 and Table 2. These databases were selected from data books and process planning departments in automotive companies, as well as from projects that have already been successfully completed. Elements of the database include the type of materials to be joined, their thicknesses, the best connection technologies and associated best setting conditions, grooves, required preheating, etc.

#	*Material 1*	*Material 2*	*Best welding technology*	*Best welding Condition*	*Ref.*
1	304 stainless steel	316L stainless steel	Spot Welding	1 mm thickness, 10,000 A, pressure of 4 kN	[17]
2	low carbon steel sheet	low carbon steel sheet	Laser beam welding	Metal sheets having thickness in the range 0.2 to 6mm, power range of 3 to 5 kW	[3]
3	Galvanized steel sheet	Galvanized steel sheet	Pulsed MAG welding	100cm/min welding speed 7.3 m/min feed rate 18-30 volt	[7]
4	Medium carbon steel	Medium carbon steel	Lap joint-Braze welding	1 mm thickness	[14]
5	AA 6111	AA 6111	cold metal transfer (CMT) welding process	Bead on a plate 3 mm, 1–2 mm 4043, Pure argon – 1.0 m/min	[8]
6	A5052	A5052	AC-MIG process	Bead on plate, 3 mm, ER5356, 1.2 mm 100 % Ar, Wire speed (600 cm/min), Current (65-98A), Gas flow rate (20 l/min), Voltage 15.6–17.6 V	[8]
7	S355 steel	S355 steel	lap joint- MAG process welding	Thickness (1.3mm), Current (70A), Voltage (17.4V)	[8]

Table 1: Sample of connection materials for similar or dissimilar welded parts.

The system's databases contain many successful results from previous projects and are able to automatically capture the results of new projects using the expert system. Rule-based AI decision systems are preferred here because the number of elements included in each parameter is limited, and expert systems are also preferred here because the decisions are definitive, there are no uncertainties, and the decisions are based on logic. ANNs (Artificial Neural Network) are also not suitable for this stage as there is no suitable amount of data with sufficient variation in the case studies.

In the second stage, each connection method was analyzed to determine its effective parameters and the effect of each parameter on the output of the process. Then optimization techniques were used for finding the optimal values combinations for each process inputs to get best parameters for the product. Optimized data are gathered for training black box of ANN models to be used for simulating each process.

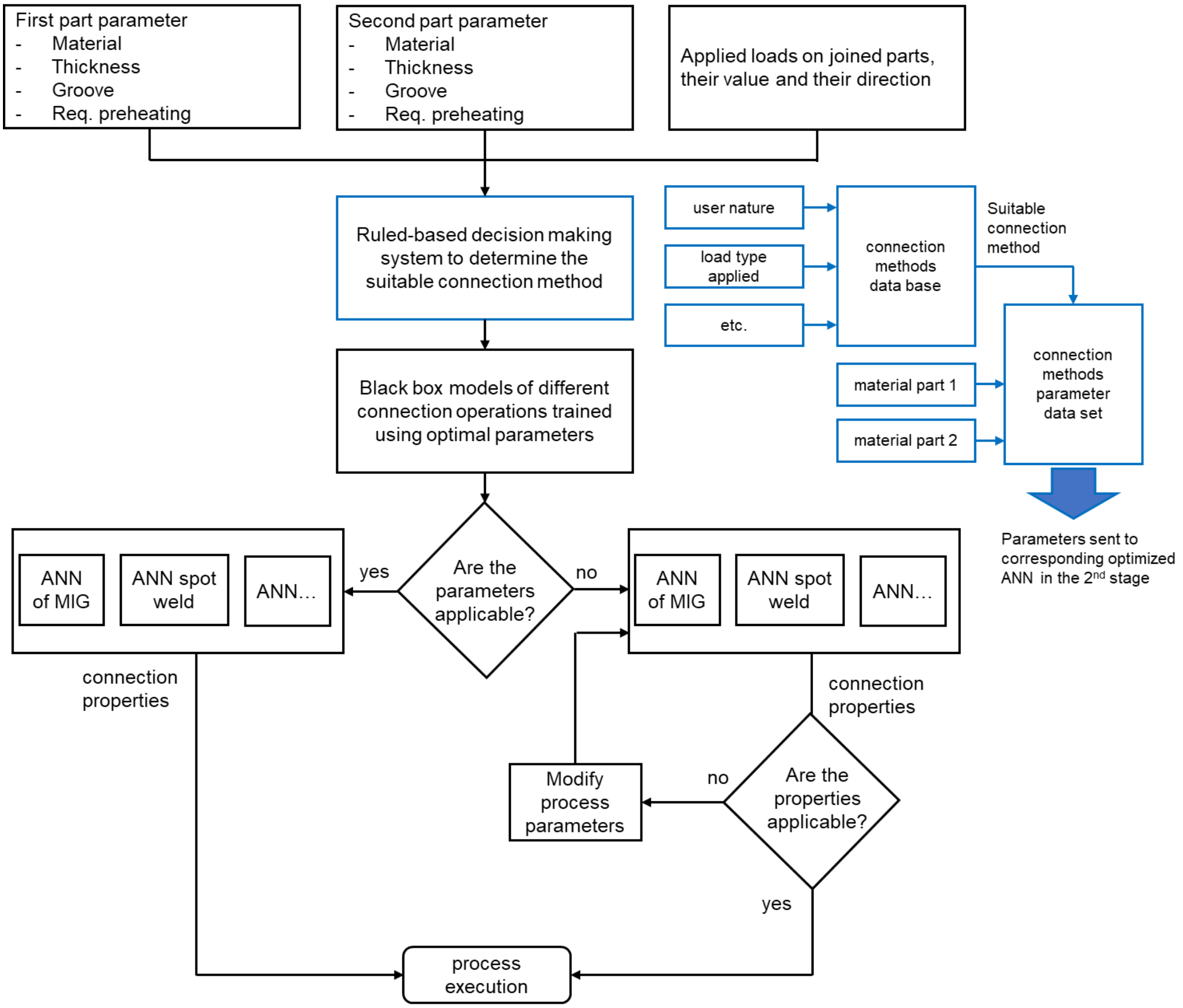


Figure 4: Intelligent system flow chart.

If the optimal operating parameters are not available for any constrain, the available parameters are to be simulated by other black box ANN models trained by crude data, so any possible defects can be recognized and evaluated either as affordable defects or not, Figure 4 shows the flow chart of both stages. Here ANNs are the most suitable AI technique as most processes are MIMO (Multi Input Multi Output).

Sometimes depending on safety, environment, or even social requirements some loads can require more safety factor during design or even some connection methods can be restricted for models to be produces for specific markets that's why these constrains are considered at the first stage.

Also, availability of materials and tools due to supply chains interruptions could make restrictions during manufacturing which could oblige us to accept less efficient processes or even some affordable defects that's why the second stage included models for process trained with crude data to give us clearer sight to determine which compromise to accept in the connection process.

Material	*Volvo V90 [11]*	*Peugeot 3008 [11]*	*Aston Martin DB11 [11]*
Aluminum	6%	5%	53%
Standard steel	27%	27%	5%
High strength steel	67%	62%	
Synthetics		65%	42%

Type of connection technology	*Volvo V90 [11]*	*Peugeot 3008 [11]*	*Aston Martin DB11 [11]*
Spot welds	5250 pcs.	4157 pcs.	
Rivets			1278 pcs.
Clinches		14 pcs.	
Weld studs	247 pcs.	83 pcs.	
Screws			52 pcs.
Seam Welds	9.3 m	150.29 m	
Adhesive Lines	79.4 m	20.22 m	152 m

Connection technology	*Project 1*	*Project 2*	*Project 3*	*Project 4*
Bolt	YES	NO	NO	NO
Welded stud	YES	YES	NO	NO
Clips	NO	NO	NO	NO
Gumdrop	YES	NO	YES	YES
Heat stakes	NO	NO	NO	NO
Nails	NO	NO	NO	YES
Rivet	YES	YES	NO	YES
Clinches	NO	NO	YES	NO
Rob scan	NO	NO	NO	NO
Screw	YES	YES	YES	YES
FDS	NO	YES	YES	YES
Spot weld	YES	YES	NO	YES
Adhesive Line	YES	NO	YES	NO
Seam Weld	NO	YES	YES	YES
Adhesive Faces	YES	NO	NO	NO

Table 2: Data base of BIW connection technologies used several automotive projects.

In order to decide whether one ANN or several ANNs should be used for each connection process, it is important to determine the parameters that affect each process. Table 3 shows the parameters that affect the MIG (Metal Inert Gas) welding process, one of the most important connection processes in the automotive industry. The MIG welding process is exemplarily chosen to demonstrate the potential of the data base and SJTT.

The parameters in Table 3 were practically studied as an example of the processes under investigation, and measurements were made to obtain raw data. One ANN was not sufficient for the simulation of such a highly non-linear MIMO process, so each measured output parameter was separated in an ANN, using the effective parameters as inputs for this ANN.

	Voltage	*Current*	*Linear velocity*	*Gas pressure*	*Gas mixture*	*Preheating*

Droplet size	$I_{Arc} \alpha \alpha$ $1/V_{Arc}$ Droplet size α V_{Arc}	Droplet size α $1/I_{Arc}$			Add O_2 decreases size	
Detachment		Frequency of detachment α I_{Arc}				
Spraying	Spraying α $1/V$				Add O_2 increase No. of drops per time	
Thickness of layer	Width α V_{Arc}					
Penetration		$P \alpha I_{Arc}$		Direct proportional	Argon + CO_2 makes higher penetration	
HAZ						Inverse proportional
Hardness			Direct prop.			
Concaveness	α V					

Table 3: Parameters affecting the MIG welding process.

5 CONCLUSION

The novel approach presented here offers a virtual framework that support automotive development and engineering processes, as well as the engineers in their daily business. The *SJTT* uses an AI-based prediction algorithm which, on the one hand, predicts the appropriate connection technology for the individual components to be joined, by using the 3D CAD model data and, on the other hand, available data sources. These data sources provide a vast number of image data combined with stored knowledge of CAE and CAM environments.

The *SJTT* is a customized virtual product that helps accelerate automotive development and engineering processes while at the same time resources are saved, competitiveness for the manufacturer will increase and CAD-CAx optimization loops will be reduced. The utilization of the *SJTT* in automotive development processes opens great possibilities for significantly shorter project duration and thus leads to earlier market entries of the automotive products.

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