Understanding the complex needs of automotive training at final assembly lines

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Abstract

Automobile final assembly operators must be highly skilled to succeed in a low automation environment where multiple variants must be assembled in quick succession. This paper presents formal user studies conducted at OPEL and VOLVO Group to identify assembly training needs and a subset of requirements; and to explore potential features of a hypothetical game-based virtual training system. Stakeholder analysis, timeline analysis, link analysis, hierarchical task analysis and thematic content analysis were used to analyse the results of interviews with various stakeholders (17 and 28 participants at OPEL and VOLVO, respectively). The results show that there is a strong case for the implementation of virtual training for assembly tasks. However, it was also revealed that stakeholders would prefer to use a virtual training to complement, rather than replace, training on pre-series vehicles.

Key words: assembly, virtual, training

1. Introduction

Final assembly lines in automotive manufacturers typically have a low degree of automation due to their requirement for flexibility and robustness (Hajarnavis, 2012). It is also common that several models of the same product share the capacity of one assembly line to support the competitiveness of automotive manufactures. As a consequence, operators on the final assembly lines are required to switch effortlessly between assembly operations for one model to the next.

Nof et al. (1997) defined assembly as *"the aggregation of all processes by which various parts and subassemblies are built together to form a complete, geometrically designed assembly or product (such as a machine or an electronic circuit) either by an individual, batch or continuous process".* Assembly operations can be considered as skill-based operations that require *procedural skill* i.e. an ability to execute action sequences to solve problems (Rittle-Johnson et al., 2001). This means that an assembly operator knows how and when certain procedures should be performed in order to accomplish a given task. By having procedural skill related to a specific assembly task, an operator will have a mental representation of the assembly task details (e.g. the number and order of steps involved, and detail of what needs to be done in each step). Therefore, training is crucial in developing operators' procedural skills when a new product and its variants are introduced. Operator training is commonly performed on pre-series (prototype) vehicles (Krammer et al., 2011). This approach has substantial limitations such as: high cost; only a low number of vehicles and product variants are built to keep the cost down; and parts wear from repeated exposure to assembly and disassembly operations.

In contrast to training on pre-series vehicles, the use of training in virtual environments has been associated with several advantages such as a standardized approach to training and flexibility in conducting, progressing and evaluating training. Kraus and Gramopadhye (2001) also argued that virtual training is cost effective for several reasons: elimination of travel expenses for trainers/trainees as training can be delivered on-site; minimising down-time as training can be flexibly undertaken around trainees' work schedule; and less demanding on personnel resources as trainees can train independently. Boud et al. (1999) found that operators who have used a virtual training system learned new procedures effectively and performed better on real assembly tasks than those using solely written instructions. Similar trends have also been shown in the application of virtual training in other areas such as aircraft maintenance (Barnett et al., 2000), machine operations (Lin et al., 2002), surgical operations (Seymour et al., 2002; Larsen et al., 2009), and the military (Gerbaud et al., 2008).

There have been many virtual training systems which were developed to aid the acquisition of procedural skills related to assembly tasks. However, most systems are aimed at supporting training of maintenance tasks in which knowledge of both assembly and disassembly are part of what is acquired during the training of the tasks (Webel et al., 2013, Xia et al., 2012; Peniche et al., 2011; Gutiérrez et al., 2010; Abate et al., 2009; Oliveira et al, 2007; Wang and Li, 2004; Bluemel et al., 2003; Vora et al, 2002); only a few are dedicated solely to support training of assembly tasks (Lili et al., 2009; Brough et al., 2007; Abe et al., 1996). On studying these publications further we also found an indication that formal user requirements elicitation was rarely conducted prior to the development of the systems. Failure to perform user requirements gathering means that the system is at risk of being unable to address users' real needs and reducing its usability (Nielsen, 1993; Maguire and Bevan, 2002). To the extent of the knowledge of this paper's authors, there are limited studies (e.g. Anastassova and Burkhadt, 2009) that focus specifically on user needs and requirements for training of assembly tasks in the context of automotive manufacturers. This paper aims to fill this gap in the hope that the information could be used to promote the development of a virtual training system that matches the requirements of assembly task training. This paper's contribution lies on its wealth of findings which were gathered from two different automotive manufacturers to reflect the complex needs of training in automotive manufacturers.

Furthermore, game-based training has received increased interest over the last decade and is applied in a variety of fields including business (Leger, 2006), education (Jong et al., 2008) and military (Beal, 2009). This popularity is attributed to the hypothesis that it can lead to skill acquisition and retention due to its ability to engage learners (Colquitt et al., 2000; Prensky, 2001) and is supported by empirical research evidence (Corbeil, 1999; Engel et al., 2009; Garris et al., 2002). There have also been indications that skills learned in game-based training environments transfer to real-life situations (Gopher et al., 1994;

Topolski et al., 2010). Despite the latest evidence of the effectiveness of game-based training there has not been any study that investigates the possible application of game-based training within a manufacturing setting in the automotive sector. This paper aims to fill this gap by investigating end users' opinions towards game-based virtual training. While this was necessarily hypothetical, as no game-based system was available yet for them to experience, the feedback was gathered in an attempt to identify potentially beneficial features for such a system and highlight areas that could be worthy of future investigation.

In summary, the objectives of this paper are as follows: 1) to investigate user needs and requirements for training assembly tasks in the context of automotive manufacturers; and 2) to investigate users' opinions towards game-based virtual training.

2. Methods

2.1. Participating companies

This study involved two automotive manufacturers (OPEL and VOLVO Group), which were chosen to exemplify the complexity of both organisation and assembly tasks in such organisations.

2.2. Interviewees

The stakeholders were identified through discussion and liaison between human factors researchers and representatives of end users of both automotive manufacturers. During the discussions, the end user representatives were encouraged to adopt broad definitions of stakeholders i.e. anyone in their organisation who is likely to use or be affected (directly or indirectly) by final assembly training. The end user representatives were requested to provide a general overview of the demographics and backgrounds for each identified group of stakeholders (see Appendix A).

2.3. The semi-structured interview and observation

A semi-structured interview was developed following a brainstorming session that involved end user representatives, human factors researchers and system developers. The interview questions were organised in five main sections: 1) roles and responsibilities; 2) workplace and work environment; 3) training; 4) process and workflow; and 5) game-based virtual training. During the development of the interview, feedback from end user representatives was obtained and used to improve the questions of the semi-structured interview. Table 1 shows the list of the questions in each category and indicates to whom these questions were directed. In order to help interviewees understand and visualise the concept of game-based virtual training, the following definition of game-based virtual training was given: a virtual training system which can be used to train assembly tasks without physical parts and could be in the form of training software that runs on a desktop computer or uses technology similar to Nintendo Wii; also the training will be game-like and perhaps involve a competition or contest.

Table 1. List of questions in the semi-structured interview

Roles & responsibilities	1.1. Summary of your role[1]
	1.2. What is your current involvement with operator training[1]
	1.3. Please provide a task level description of the operators job, i.e. the detail of what they actually do[2]
	1.4. Does the task that the operators perform vary considerably, i.e. do they do many different operations, or are they mostly similar?[3]
	1.5. What is your production rate? i.e. how many assembly operations are required per hour? [2]
	1.6. Do any of the assembly tasks pose particular difficulties to the operators? Do any tasks

	cause frequent problems?[1]
	1.7. How are issues with assembly operations recorded?[1]
	1.8. Do you receive feedback on assembly operations which are difficult or time-consuming? If so, how?[4]
Workplace & work environment	2. What are the conditions in which the operators work? E.g. shift work, noise, lighting, please describe the physical workplace and social environment[2]
Training	3.1. What are the tasks that the operators need to be trained for (e.g. fitting components on vehicle assembly lines)?[2]
	3.2. How are they currently trained to do these tasks?[2]
	3.3. What is the timeframe of the training (i.e. when does it take place in relation to vehicle launch?)[3]
	3.4. What is your opinion of the training?[1]
	3.5. What are the key skills or knowledge being taught?[1]
	3.6. What is good about the current approach to the training?[1]
	3.7. What are the difficulties with the current approach of the training, or what problems exist? [1]
	3.8. Can you suggest how to improve the training?[1]
	3.9. What do you consider the most important performance measures and goals?[1] Human: Of the operators' job (e.g. time, errors,…) Operational: Of the training (e.g. operator must complete task correctly XX% of the time) Business: (e.g. a Timeframe reduction for the training)?
	3.10. What are the requirements for authoring training sessions (time available, man-power etc.)?[5]
	3.11. Does training improve productivity? If so, how?[5]
Process & workflow	4.1. What software tools do you currently use as part of the training process? (e.g. CAD systems or production planning software?)[1]
	4.2. What is the communication/information flow (i.e. who provides what information to who)? [1]
	4.3. What information is required by planners/trainers?[1]
	4.4. Within the vehicle development lifecycle, what information related to training is required & when? i.e. when are engineers required to specify assembly instructions[1]
Game-based virtual training	5.1. What are your initial thoughts about training using virtual systems?[1]
	5.2. Do you think this approach could improve training? [1]
	5.3. What problems would you anticipate? [1]
	5.4. What are your initial thoughts about a game-like system for training?[1]
	5.5. What are your thought on the capture and feedback of assembly issues to the product designers and manufacturing systems engineers? [1]
	5.6. Do you own, use or have been tried a X360, PS3 or WII based game console? What is your impression or experience controlling a game using a wireless controller?[1]
	5.7. Would you like to be involved in the VISTRA project? i.e. can we contact you again to obtain your feedback on the developed technologies?[1]

Note: [1]all stakeholders; [2]operators; [3]operators, engineers, supervisors; [4]engineers; [5]all stakeholders except operators

A total of 45 participants were involved in the interviews, of which 17 participants were from OPEL and 28 participants were from VOLVO (see Table 2). The semi structured interviews lasted approximately 30 minutes to one hour, with between one and four participants being interviewed together in each session. During the interviews, participants were encouraged to talk freely. Involvement from the interviewer was limited to prompting participants to provide more details or expand on key issues. Due to concerns over commercial sensitivity and the resources available for analysis, responses from participants were mainly recorded through handwriting.

Table 2. Stakeholders, number of participants and their average number of years in current position

	Stakeholders	**Number of participants**	**Average number of working years in current position**
OPEL	Manufacturing System Engineer Manager	1	20
	Manufacturing System Engineers	2	12
	Virtual Engineers	2	Information not provided
	System Owner	2	12
	Launch Team Manager	1	32
	Core Team Manager	1	Information not provided

	Core Team	2	22
	Launch Team	1	24
	Supervisors	2	18
	Team Leaders	2	20.5
	Operators	2	24.5
VOLVO	Design Engineers	2	3.5
	Production/Introduction Engineer	3	3.3
	Virtual Manufacturing Engineers	2	8
	Technical Preparation Engineer	1	18
	Team Leaders	3	7.5
	Pilot Plant Team	3	9.8
	Operators/Key Operators	14	2.5

Observations at the final assembly lines lasted between 45 minutes to 1 hour. Notes regarding final assembly tasks and the environment of assembly lines were taken. Short informal discussions with operators were also performed when required and/or possible. The observation complemented the results of the semi-structured interviews regarding the details of workplace, work environment and assembly tasks (interview question 1.3 and 2).

2.4. Data Analysis

The interview and observation results were analysed with five qualitative methods. The choice of these methods followed the guidance provided by Leonard et al. (2006) which considered factors such as the purpose of the study (explanation driven or implementation driven) and availability of resources (time, experience, funding and previous research). A detailed description of the methods used is given below:

1. *Stakeholder analysis* has been recognized as important to ensure the effectiveness of product/system design and development in various fields (Amiri, et al., 2012; Atkinson et al., 2001; Neuman, 2004; Brooks, 1998; Neary and Sinclair, 1998). In this study, the stakeholder analysis helped to identify and examine users that are likely to be somewhat affected by implementation of a training approach. The stakeholder analysis was based on the responses from interview questions 1.1 and 1.2.
2. *Timeline analysis* combines functions or tasks with time-related information. It is useful to create plots that show the temporal relationship among tasks, their length and timing (Nemeth, 2004) as well as to assess task allocation and communication requirements identification (Kirwan and Ainsworth, 1992). Timeline analysis was based on the responses from question 3.3 and 3.10.
3. *Link analysis* is useful to provide descriptions of the interrelationships between elements/components and their frequency (Chapanis, 1959). Although it is traditionally used to arrange equipment and individuals in a workplace and arrange controls and displays on a console, it has also been used for other purposes such as monitoring and analysing communications in rescue operations (Thorstensson, et al., 2001) and finding information needs (Albinsson et al., 2003). Link analysis was based on the responses from questions 1.7, 1.8, 4.1, 4.2, 4.3 and 4.4.
4. *Hierarchical Task Analysis (HTA)* is a form of task analysis to study actions and cognitive processes that are required by an operator in order to complete the system goals (Kirwan and Ainsworth, 1992). It can be applied to a variety of applications (Stanton, 2004). The HTA in this study was based on the responses from questions 1.3, 1.4, 1.5, 2 and observation results.
5. *Thematic analysis* provides a descriptive presentation of qualitative data by identifying common topics and categorizing the qualitative data under suitable themes (Franzosi, 2004). It has been

shown to successfully support development of technological products (Minocha and Reeves, 2010; Coleman et al., 2010; Artman and Zällh, 2005; Sawasdichai and Poggenpohl, 2002). Because it is guided by a specific research question or sub questions by making inferences of an intended population (Lapan et al., 2012) it can be used to provide answers for design questions that could not be directly addressed by the analyses described above. For this study, thematic analysis helped to select, focus and transform qualitative data into manageable information segments to show their patterns. Thematic analysis was mainly based on the responses of questions that were not used in other analyses.

On completing the data analysis, the results of the data analysis were reported back to, and verified by, end-user representatives. Any found inconsistencies, especially related to the timeline analysis and link analysis, were then corrected.

2.5. Identification of training needs, training requirements and potential features of game-based virtual training

The results of data analysis were used to identify training needs and drafted as a subset of the user requirements. Features of game-based virtual training that could potentially be beneficial were also drafted. These drafts were presented to the end user representatives and the system development experts. The representative end users judged the importance (high, medium, low) of each identified user requirement/potential feature while the system development experts judged the technical feasibility (high, medium and low) of potential features. During the refinement process, answers to questions such as "how important are the different requirements/features for the users?" and "what is the consequences for users if we do not implement a specific requirement/features?" were continually assessed. In this process, human factors researchers acted as "independent auditors" to provide more objective perspective of stakeholder positions and interests (Crosby, 1992).

3. Results

For each type of data analysis a summary of the relevant semi-structured interview results will be presented and is followed by an account of the analysis results.

3.1. Stakeholder analysis

The responses from questions 1.1 and 1.2 are shown in Appendix B, which lists all stakeholders, their roles and responsibilities and their current involvement in training. We observe that both automotive manufacturers follow the commonly adopted "on-the-job training" approach which requires a trainee to work side-by-side with a trainer on the assembly line. Five categories of stakeholders were identified based on their involvement with training i.e. trainee, trainer, coordinator, indirect benefactor and system champion. Table 3 shows the detail for each category. The stakeholder analysis also revealed that stakeholders' involvement was affected by whether the training takes place at the pilot line or assembly line.

Table 3. Categories of stakeholders that were identified from responses of questions 1.1 and 1.2

Stakeholder category	Stakeholders	Involvement with current training
Trainee	Team leaders (OPEL), Key Operators-Teachers (VOLVO)	Being trained at pilot line (dedicated training centre/location) by launch team (OPEL) or pilot plant team (VOLVO).

	Operators	Being trained at assembly line by Team Leaders (OPEL) or Key Operator-Teachers (VOLVO).
Trainer	Launch team (OPEL), Pilot plant team (VOLVO)	Train experienced operators at pilot line.
	Team leaders (OPEL), Key Operators-Teachers (VOLVO)	Train operators at assembly line.
Coordinator	Launch team manager (OPEL), Pilot Plant Team Coordinator (VOLVO)	Train experienced operators at pilot line.
	Supervisors (OPEL), Team Leaders (VOLVO)	Managing training for operators at assembly line.
Indirect benefactor	Core Team, Manufacturing System Engineers (OPEL), Production Engineers (VOLVO)	Rectifying incorrect assembly operations at main assembly line.
System champion	System Owner (OPEL), (VOLVO)	Maintain the system.

3.2. Timeline analysis

Responses from questions 3.3 and 3.10 for both automotive manufactures are summarised in Table 4. Detailed information from the responses was used to create timelines (see Figure 1) which show the succession of events prior to the training of new products at both automotive manufacturers.

Table 4. Summary of responses to questions related to timeline analysis

Interview question	Summary of responses
3.3. What is the timeframe of the training (i.e. when does it take place in relation to vehicle launch?)	Training took place towards the end of vehicle launch at both automotive manufactures. A staggered approach was adopted i.e. train the trainers at pilot line who then train operators at assembly line.
3.10. What are the requirements for authoring training sessions (time available, man-power etc.)?	There is no specific duration of a training session, especially for a training session at assembly line. A training session at an assembly line largely depends on the availability of the trainer. The pre-series vehicle is required for training at both pilot and assembly lines.

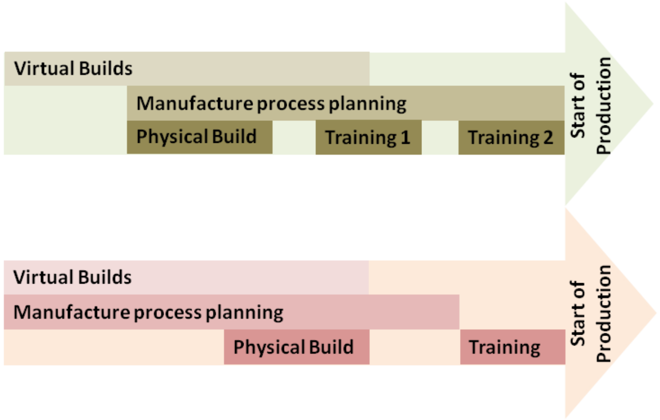

Figure 1. Timeline analysis results of OPEL (top) and VOLVO (bottom)

The timelines show that the succession of events prior to the commencement of training of new products at OPEL and VOLVO are similar. Virtual builds, which precede all other events, bring product and manufacturing engineers together to identify and resolve any issues related to the design (at an early stage of product design) and assembly processes of products (at a later stage of product design). Virtual builds are aided by software that accommodates 3D simulation of parts and assembly processes. This is followed by physical builds, where a mock up is created by the Launch Team (OPEL) or Pilot Plant Team (VOLVO) and used to further identify and resolve any issues that are missed in the virtual builds. Virtual builds and physical builds are parts of the product design process and are aimed at refining the design and assembly planning of a new product. They are part of the current training.

Training on pre-series vehicles only commences once the virtual build and physical build are completed. This takes place after a certain time gap and is performed at two different locations: pilot and main assembly lines. This time gap is required to provide adequate hardware (training vehicles) and to organise the training sessions. Although the timeline shows that there is a time period dedicated to train operators for a new product, the stakeholders mentioned that due to various factors (e.g. limited hardware/pre-series vehicle to train, availability of trainers, and productivity pressure on the lines) assembly line training is frequently shortened.

3.3. Link analysis

Responses from questions 1.7, 1.8, 4.1, 4.2, 4.3 and 4.4 are summarised in Table 5. Detailed information from the responses was used to create link diagrams (Figure 2) which show the information flow and relationships among stakeholders.

Table 5. Summary of responses to questions related to link analysis

Interview question	**Summary of responses**
1.7. How are issues with assembly operations recorded?	Issues related to assembly operations found during training at the assembly and pilot lines are recorded and collected by the Launch Team (OPEL)/Pilot Plant Team (VOLVO)/ who will then pass them to Manufacturing Engineers (OPEL)/Production Engineers (VOLVO). Issues related to assembly operations that are found once a product has been launched are recorded by Team Leaders (OPEL/VOLVO) and handled by Core Team (OPEL)/Technical Preparation Engineers (VOLVO).
1.8. Do you receive feedback on assembly operations which are difficult or time-consuming? If so, how?	During training at assembly and pilot lines, Manufacturing Engineers (OPEL)/Production Engineers (VOLVO) receive feedback on assembly operations which are difficult/time consuming. No further feedback is received by the two stakeholders above once a product has been launched.
4.1. What software tools do you currently use as part of the training process? (e.g. CAD systems or production planning software?)	Both OPEL and VOLVO use commercial CAD and production planning software during virtual builds and production planning. However, no software is used to support training. Assembly sequences are printed and distributed on paper.
4.2. What is the communication or information flow (i.e. who provides what information to who)?	Detailed information is shown in Figure 2.
4.3. What information is required by planners*/trainers? *: engineers	Manufacturing engineers require information regarding assembly issues so that they can make adjustments on product design and assembly operations. Trainers require information on relevant assembly sequences and the reasons why assembly sequences or steps have to be done in certain ways.
4.5. Within the vehicle development lifecycle, what information related to training is required & when?	Detail information is shown in Figure 2.

Figure 2 shows that, for a new product, there is already a system in place to capture assembly issues that indirectly connect operators and manufacturing engineers (OPEL)/production engineers (VOLVO). Once a product is launched, a different mechanism to capture assembly issues is applied. This mechanism keeps the manufacturing engineers (OPEL)/production engineers (VOLVO) out of the loop.

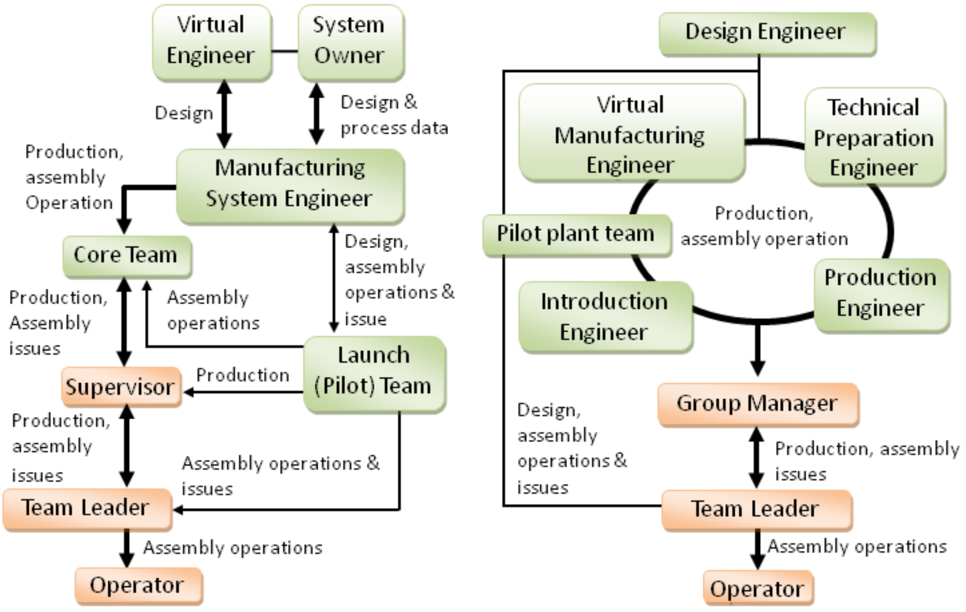

Figure 2. Link analysis results for OPEL (left) and VOLVO (right)

3.4. Hierarchical Task Analysis (HTA)

Table 6 shows a summary of the responses from 1.3, 1.4, 1.5 and 2 while the following summarises relevant findings from the observation:

1. Operators at OPEL are required to perform assembly tasks in fast moving assembly lines while operators at VOLVO are required to perform assembly tasks with an appropriate speed (neither too fast nor too slow), especially for assembly tasks which involve more than one operator.
2. The majority of assembly operations at VOLVO are collaborative assembly operations due to the size and weight of parts that were involved in assembly tasks.
3. There is a higher need for assistance tools at VOLVO such as lifting devices due to the size and weight of assembly parts.

Table 6. Summary of responses to questions related to hierarchical task analysis

Interview question	**Summary of responses**
1.3. Please provide a task level description of the operators job, i.e. the detail of what they actually do[2]	Detail information is shown in Figure 3a and Figure 3b.
1.4. Does the task that the operators perform vary considerably, i.e. do they do many different operations, or are they mostly similar?[3]	Operators are required to work at different stations or work cells. Rotations at OPEL are limited among work stations (up to 16 assembly operations), whereas rotations at VOLVO could either be among assembly cells (up to 24 operations) or stations (up to 96 assembly operations). The number of product variants at VOLVO is larger than OPEL because VOLVO allows their customers to custom make their orders; some variants might appear only once at the assembly line. Therefore, operators at VOLVO are required to have an ability to understand SPRINT i.e. a paper-based instruction of assembly procedures which contained technical terminologies and codes that described assembly procedures. An understanding of technical terminologies and codes allows Operators to perform assembly tasks for a new variant at the main line, even if they had never encountered it before.
1.5. What is your production rate? i.e. how many assembly operations are required per hour? [2]	Cycle time at each work station is 1-2 minutes at OPEL and up to 14 minutes at VOLVO.
2. What are the conditions in which the operators work? E.g. shift	Plants at OPEL & VOLVO are both bright and noisy. At OPEL, each team leader is responsible for up to four work stations, with 1-2 operators at each work

work, noise, lighting, please describe the physical workplace and social environment[2]	station. At VOLVO, each team leader is responsible for two to four work stations that consisted of four assembly cells with 1-2 people at each cells. A work station at VOLVO contains up to 16 Operators (4-6 Operators at OPEL) and up to 24 different operations (16 operations at OPEL).

Combining the findings from the observation results and responses from questions 1.3 and 2, HTAs were created for both automotive manufacturers (see Figures 3a and 3b).

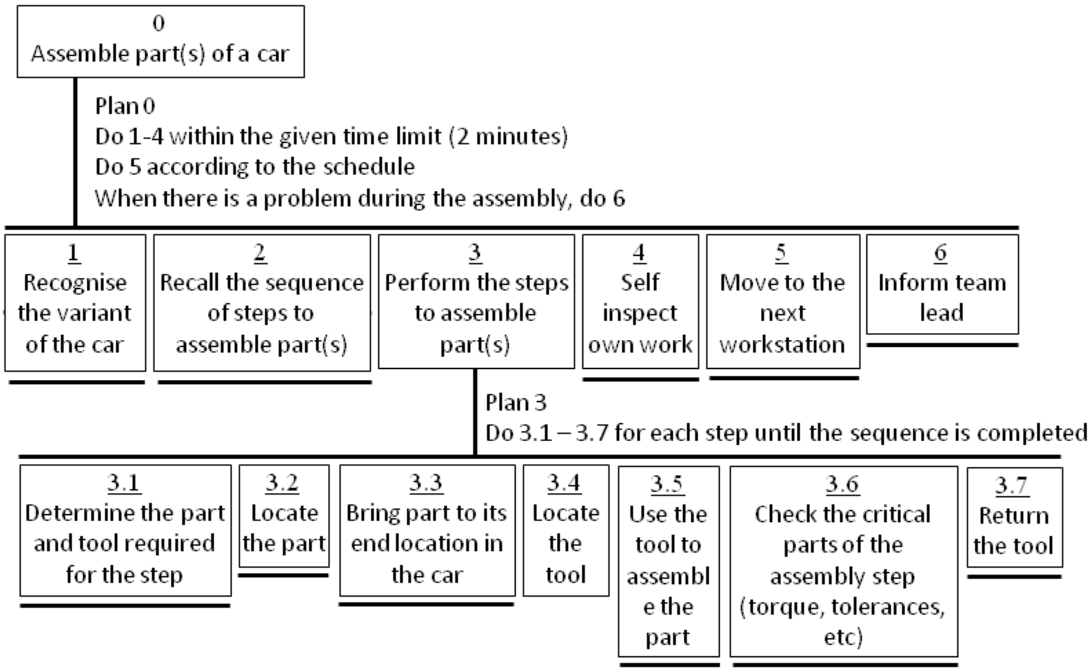

Figure 3a. HTA diagram of an assembly operation at OPEL

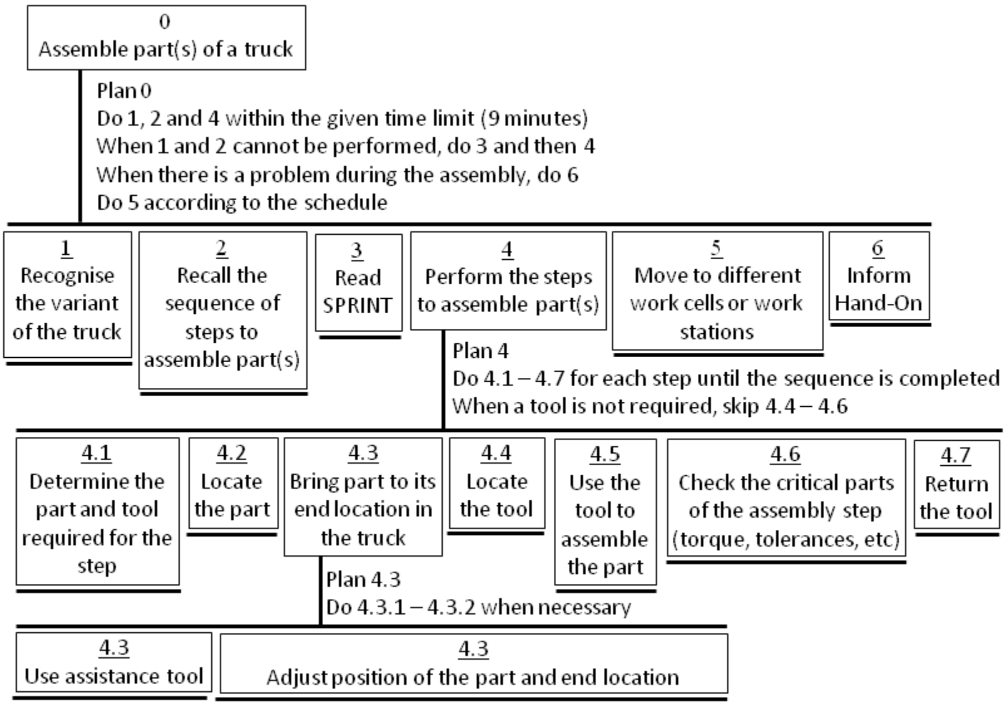

Figure 3b. HTA diagram of an assembly operation at VOLVO

Table 7. Summary of responses to questions related to thematic analysis. Unless otherwise stated, the summary applies to both automotive manufacturers.

Interview questions	**Summary**
1.6. Do any of the assembly tasks pose particular difficulties to the operators? Do any tasks cause frequent problems?	Assembly operations that involve awkward and non-ergonomic postures were frequently cited. Another issue is harness wiring as the assembly instruction is difficult to understand, especially related to the cable behaviour.
3.1. What are the tasks that the operators need to be trained for (e.g. fitting components on vehicle assembly lines)?	Assembly operations, assembly sequences and how to understand paper-based assembly instruction.
3.2. How are they currently trained to do these tasks?	Operators at assembly lines are trained by experienced operators who had been trained at pilot line. A trainer gives a demonstration of the assembly operations/sequences, followed by a trainee performing the operations/sequences. Theoretical background is only given when there is enough time.
3.4. What is your opinion of the training?	There is no standard method of training. There is not enough time and resources (hardware and trainers) to deliver the training.
3.5. What are the key skills or knowledge being taught?	How to read paper-based assembly instruction, parts recognition (part appearance and number), where and when the part has to go, assembly time, quality check.
3.6. What is good about the current approach to the training?	The training is done by experienced operators; there is freedom to ask questions.
3.7. What are the difficulties with the current approach of the training, or what problems exist?	Lack of training due to time and resources. A lack of standard on what is being trained. The number of variations that could be learned through training was really limited. Only a few operators mastered assembly operations other than those within their stations/cell.
3.8. Can you suggest how to improve the training?	Provide structured training; allow dedicated time and resources for training.
3.9. What do you consider the most important performance measures and goals? i.e. i) Human: of the operators' job e.g. time, errors; ii) Operational: of the training e.g. operator must complete task correctly XX% of the time; iii) Business e.g. a timeframe reduction for the training.	Human: quality of assembly, errors, resolving problems independently Operational: completing the assembly sequence within the required time Business: better training prior to launching the product, quality.
3.11. Does training improve productivity? If so, how?	Yes. It reduces the rework due to poor quality.
5.1. What are your initial thoughts about training using virtual systems?	Most stakeholders had positive views on training using a virtual system. Stakeholders that have experienced software and virtual system suggested factors that had to be considered in creating a virtual training system.
5.2. Do you think this approach could improve training?	All of the stakeholders could foresee the benefit of a virtual training system in complimenting the current hardware-based approach to training.
5.3. What problems would you anticipate?	Acceptance, ease of use, realism, system maintenance and updates.
5.4. What are your initial thoughts about a game-like system for training?	Nearly all stakeholders were positive about a game-like system for training. However, the level and type of competition in the game should be considered carefully.
5.5. What are your thought on the capture and feedback of assembly issues to the product designers and manufacturing systems engineers?	Most stakeholders agreed that capturing the feedback and assembly issues would be useful. There was also a suggestion to extend this to capturing knowledge and the experience of operators.
5.6. Do you own, use or have been tried a X360, PS3 or WII based game console? What is your impression or experience controlling a game using a wireless controller?	More than half of the stakeholders had tried game consoles.
5.7. Would you like to be involved in the VISTRA project? I.e. can we contact you again to obtain your feedback on the developed technologies?	All of stakeholders, except one, gave their consent to be contacted for further involvement in VISTRA project.

3.5. Thematic Analysis

Table 7 provides a summary of responses from interview questions that were not used in other analysis. The main themes derived from all shown responses are described below. Bold font is used to highlight the theme.

The interview revealed that one of the main drawbacks of the current approach to training is the fact that actual **training time can be shorter and less extensive than the initial training plan, resulting in a lack of training for operators.** An example of a comment that reflected this circumstance was given by a team leader: *"One day for training is good, but we don't have time. Difficult for new people to deal with time stress. Quality is most important. It is right people on right jobs, because some people find some operation very difficult, so they need to change when it is possible. Training procedure in theory is good, but sometimes it is not possible to give enough time for training - explaining documentation to workers, why things are important, safety issues…"*.

Another drawback of the current training approach, mainly identified by engineers (OPEL-manufacturing system engineer, VOLVO-production engineer, design engineer) is **the lack of control of what is being delivered in training.** This was reflected by the following comment: "*Operator is taught by an experienced operator.....The experienced operator will teach his own way. You don't really know if the operator really understands how to do the job. Different educators teach in different ways and maybe the wrong way. There are different ways to do a job from its technical description but no one does it the same way which can lead to quality issues. You should learn the important stuff. Base knowledge is not being taught leading to quality issues....".*

Most of the stakeholders (OPEL-manufacturing system engineer, system owner, virtual engineer, operators, team leader, core team, launch team; VOLVO-virtual manufacturing engineer, technical preparation engineers, team leaders, pilot plant Team, operators), irrespective whether or not they have had experienced with game consoles, **expressed positive responses towards game-based virtual training** by stating that it would be fun, interactive, engaging and might be a "good way" to get acceptance. They also thought that introducing it in a competitive manner would possibly drive operators' efficiency although they emphasised that the training solution should make clear trainees are not being evaluated individually and that the system should be agreed by work councils i.e. the organisations (trade unions) that represent operators at the assembly lines.

Interestingly, the general initial thought on game-based virtual training **was that this approach to training should not replace training on pre-series vehicle as operators need to get a touch and feel for objects' mass and size**. This concern was mostly based on stakeholders' experiences that, while "everything looks perfect and easy on paper and computer", difficulties in assembling parts are likely to occur in real-life situations because of various factors such as restrictions imposed by the parts' weight, lack of fit between parts, lack of flexibility of parts (i.e. wiring harnesses). Thus, the know-how on techniques or ways to remediate the difficulties could only be obtained by handling real-parts. Nonetheless, all of stakeholders viewed game-based virtual training as a good additional tool to have for better preparation in knowing the tools, parts, sequences, etc. prior to hardware training and real production. Some of the benefits which were identified by stakeholders include: i) helping operators to learn assembly operations by enabling parts visualisation in 3D rather than 2D drawings ahead of their training on pre-series vehicle; ii) providing opportunities to train on more product variants that otherwise would not be possible due to limited hardware provision; iii) reducing cost and time for training; and iv) providing an opportunity to involve operators in the development of the car at an earlier stage.

Stakeholders who have experienced using software as part of their roles (OPEL-System Owner, Manufacturing System Engineer Manager, Virtual Engineers, Launch Team, Core Team; VOLVO- Virtual Manufacturing Engineer, Technical Preparation Engineer, Pilot Plant Team, Design Engineers) highlighted **the need to link a virtual training with existing software systems**. Stakeholders who have had experience in using virtual systems (e.g. OPEL-manufacturing system engineers, virtual engineers, launch team; VOLVO-design engineers, production engineers, pilot plant team) also stressed the importance of "a realistic virtual training" which refers to the ability of a virtual training to represent conditions that were encountered in real assembly line. Some examples that were given included: parts' behaviour, time pressure, force feedback during parts' fitting, tolerance issues, etc.

With regards to anticipated problems of game-based virtual training, most of stakeholders (VOLVO- Virtual Manufacturing Engineer, Technical Preparation Engineer, Team Leaders, Operators, Pilot Plant Team; OPEL-Manufacturing System Engineer Manager, Virtual Engineers, System Owners, Virtual Engineers, Operators) cited **acceptance of the technology as a potential issue, with age and technology affinity as the given causes.** Two examples of comments from a team leader and an operator provided a good summary for this view: "*… need to relate training to product. Most people here don't know what an axle is at first. Might have use for training of variants, if seen in real life first. Can't teach weight of part so have to learn this in real life. Expect big individual differences in acceptance. People who worked for many years are doing things their way and don't like change*" (Team Leader); "*Old ones would not accept it. They're negative. They've been here long. Don't want to change. Young people would see it as fun*" (Operator). Therefore, they emphasised that the game-based virtual training should be easy to use and not required training in order to use it. If separate training was required to interact with the virtual training, they were adamant that virtual training might be too much work to add on to training on pre-series vehicle. This was reflected by a comment of a team leader: "*May be too much work for us, may be too much work for workers too, may be need some time to understand it.*"

4. Discussion

The results of the data analyses were used in generating training needs, requirements and potential features of game-based virtual training. It was revealed there were two needs related to assembly training. The first was the need for early deployment of training. This need (identified from the time line and thematic analyses) emerged from the fact that the current training system reliance on the provision of pre-series vehicles resulted in a lack of training for operators. This was because the training was often delivered too close to the start of real production at the assembly line. The second need (identified from the link analysis and thematic analysis) was standardised content of assembly training. This need emerged from the fact that the current training system relied heavily on the autonomy of experienced operators to manage and deliver training with limited or no possibilities for stakeholders who have an overall overview of assembly operations (e.g. manufacturing engineers (OPEL)/production engineers (VOLVO)) to contribute to or control the training content. Both of these needs could potentially open an opportunity and present a strong case to support implementation of virtual training for automotive manufactures. Provided that digital information related to part information and assembly procedure is available, virtual training can be delivered earlier and easily fulfils the need for a standardised training content and approach. Based on the interview results, a sub set of requirements related to what assembly training should contain and how it should be measured was established (see Appendix C). The interview results were also used to identify potentially beneficial features of game-based virtual training that could be worthy of investigations in further studies (see Appendix D). As a result of OPEL and VOLVO differences in their products' customisation and assembly arrangements, there were observable variations towards training requirements and potential features of game-based virtual training.

Most stakeholders had positive views towards game-based virtual training. This was likely due to game-based virtual training being viewed as more motivating than traditional form of training (Gee, 2003; Prensky, 2001). Research has shown that game-based virtual training can provide players with a continuous variety of emotional conditions or psychological stimuli which in the end influences motivation (Dondi et al., 2004). However, game-based virtual training is also known to be ineffective due to various factors such as inappropriate methods/means to assess learning outcomes and poor contextualisation of games into a meaningful learning context (Squire, 2004; Egeneldt-Nielsen, 2005). Another aspect which needs to be considered when introducing game-based virtual training is the negative effect of competitiveness on the learning process (e.g. competitiveness resulting in certain individuals to focus on performance/score at the expense of learning (Harviainen et al., 2012), demotivation when losing (Moseley et al., 2009)) and potential ethical/legal issues. Prior to the application of game-based training within automotive manufacturers, it is important that work councils are involved to resolve various issues such as: "are scores of training made explicit among operators?", and "is competition among operators allowed?" As shown in this study, competitiveness, which is one of attributes of game-based virtual training, would likely have to be minimised if the work council objected to the above questions.

However, the interview results also showed stakeholders' reservations towards replacing existing training with game-based virtual training. Stakeholders asserted that such training should act as a complement to training sessions on pre-series vehicles. This finding supports other studies on the ability of virtual environment to "replace" real life encounters (Zhang et al., 2004; Chi Wai et al., 2011). The most common reason given was the need for tactile feedback while handling parts and the associated assembly steps. Thus, it is likely that, until virtual training could provide similar tactile feedback to those in real life, the role of virtual training in automotive manufacturers will remain complementary to training sessions on pre-series vehicles. While this somewhat limits the current applicability of game-based virtual training, in the meantime, game-based virtual training could be introduced as a preliminary on-site independent training session that allows trainees to recognise parts and learn assembly steps interactively while pre-series vehicles for training purposes are built. Furthermore, as resources for pre-series vehicles training are likely to be limited due to the time availability of the trainers and small number of pre-series vehicles, game-based virtual training could also be used simultaneously during the pre-series vehicles training. Thus, pre-series vehicles training will provide trainees with the "touch and feel" and know-how to remediate possible difficulties while performing assembly in real-life whereas the game-based virtual training will teach trainees the assembly steps and part recognition. The Technology Acceptance Model (TAM), which was proposed by (Davis, 1989) postulated that the perceived level of usefulness significantly affects user acceptance of information technology design. Therefore, to increase the level of potential users' acceptance of a virtual training within the context of automotive manufacturers, it is essential that potential users are clearly informed that the role of virtual training is to complement existing training on pre-series vehicles and will only serve as a sole means of training when training on pre-series vehicles is not available.

The interview results also revealed stakeholders' opinions towards potential features that could likely improve game-based virtual training system's fidelity i.e. the ability to capture and transfer real life situations to a virtual environment. Their most commonly suggested features were compiled under the category of "high realism" (appendix D). A further observation of the potential features in appendix D shows that most of the suggested approaches related to "high realism" category belong to psychological fidelity (the degree to which simulated tasks reproduce behaviours that are required for the actual, real-world task) with only a few under the category of physical fidelity (how a virtual environment and its component objects mimic the appearance of their real-world counterparts) i.e. simulation of appearance of parts, simulation of parts behaviour for flexible parts. A correct blend between the two is crucial for successful virtual training, bearing in mind that psychological fidelity is associated more with positive transfer of training than physical fidelity and that the two are not necessarily positively correlated (Stone, 2008). While the compilation of features that support real-life encounters were obtained under the context of game-based virtual training; some of them would likely be applicable on other virtual training related to assembly tasks that aim to transfer a trainee's recognition of product variants' and parts' appearances and their behaviour from a virtual environment setting to a real-world setting.

This study also identified that, in addition to training assembly operations, stakeholders viewed game-based virtual training as offering the potential to be used as a platform for knowledge sharing between stakeholders. Wang and Noe (2010) defined knowledge sharing as: "the provision of task information and know-how to help others and collaborate with others to solve problems, develop new ideas or implement policies or procedures". It has been shown to contribute to reduced production costs, faster completion of new product development projects, improvements in team performance, and innovation capabilities (Wang and Noe, 2010). Studies have shown that a functionally segmented organizational structure likely hinders knowledge sharing across stakeholders within the various functions (Lam, 1996; Tagliaventi and Mattarelli, 2006). Virtual training can address this issue by allowing experienced operators to share their best practices not only with other operators but also with engineers who can then decide whether to exploit their practices or modify them. A study has shown that workers with more experience are more likely to share their expertise and have positive attitudes toward knowledge sharing (Constant et al., 1994). Possible exploitation of shared best practices can range from inclusion of best practices as part of work standardization to utilisation of best practices to support future product and process design.

As a consequence of the level of operators' computer self-efficacy, stakeholders desired game-based virtual training for assembly tasks that can be used without extensive training. While this view was obtained under the context of game-based virtual training, this attitude would likely be transferrable for other virtual training which involved low-level computer self-efficacy. Computer self-efficacy (or perceived computer self-efficacy), which refers to an individual's judgement of his her ability to use a computer (Compeau and Higgins, 1995), and computer anxiety are important determinants in influencing an individual perception of a technology's ease of use and acceptance (Agarwal, et al., 2000). Existing virtual environment usability criteria (Stanney et al., 2003; Gavish et al., 2011) could be used to assist decisions regarding user interface design of virtual training. It is also important to avoid "the temptation to integrate a novel device simply because it would become an attractive and attention-grabbing gimmick" (Stone, 2008). Difficulties with technology or interface in which the training content is delivered have been cited as a key frustration source and a reason for low completion rates in e-learning programs (Frankola, 2001). Stedmon and Stone (2001) argued that human-centred knowledge and expertise is required to ensure full utilisation and exploitation of technology-based training. Therefore, the choice of interaction devices should take into account end-users' capabilities/limitations and the nature of the task to be trained. For assembly operations, alternative input devices such as a visual gesture interface (O'Hagan et al., 2002) which allows a user to perform natural movement to select, move and grab components of virtual objects could be one possible solution. While this paper has successfully identified potential beneficial features of virtual training, it should be noted that the stakeholders involved in this study had either little or no experience in actually using virtual training and may not be accurately predicting their actual usability with such a system.

Involvement of the end user representatives to identify stakeholders was clearly beneficial as they were able to perform this task with ease and accuracy due to familiarity to their organisations. The use of semi structured interviews was useful as it ensured that important topics were covered while simultaneously enabling stakeholders to have the freedom to explain and expand their views. In addition, performing interviews with more than one stakeholder of the same job function proved to be beneficial as this facilitated discussion among them during the interview. A drawback of this study is the lack of input from potential end users during the refinement of the training requirement subset and potential features of game-based virtual training, relying instead on end-user representatives. There is a possibility that misjudgement occurred while weighing the importance of each requirement/potential feature. This could be caused by conflicts of interest, especially in circumstances where representative end users have stakes towards an issue, and/or the representative end users leaning more towards a managerial than end user role. The combination of representative end users and researchers within this study provides the opportunity for researchers to draw on the contextual insight of representative of end users. It also enabled representative end users to gain insight into how their assumptions or conflicts of interest may cause bias. This approach is mostly suitable when end-users' involvement during the refinement process is impractical, as is the case in this study.

This paper found the usefulness of employing various data analysis methods to identify training needs, generate a subset of training requirements and compile potential features for game-base virtual training environments. The analyses complemented each other by providing different insights into the work organisation and training approaches at both automotive industries. This eventually allowed the identification and extraction of training needs and requirements from various perspectives. The graphical representation that was adopted in link analysis, timeline analysis, and HTA was found to be advantageous in supporting verification by end-user representatives. Thematic analysis, although highly resource-demanding in comparison to other analysis methods, provided more detailed information regarding views of users on existing training approaches or a hypothetical game-based virtual training system.

5. Conclusions

This paper has performed a comprehensive user study to inform the training needs, a subset of training requirements, as well as potential beneficial features of game-based virtual training for assembly tasks. This study presented a strong case towards the need for an implementation of virtual training for assembly tasks. However, the preference of stakeholders to adopt virtual training as a complementary training to the existing training on pre-series vehicles should also be considered. Different approaches in the organisation of assembly work and business approaches in meeting customer demands have also been shown to have direct impact on training requirements and how game-based virtual training should be designed. The study benefited from a team that consisted of human factors researchers, representatives of end users and system developers.

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APPENDIX A - Level of education, technology awareness, language skills and the likelihood in embracing new technology for identified stakeholders

	Stakeholders	**Level of education**	**Technological levels of skills & awareness**	**Language skills**
OPEL	Operator	Trained to skilled workers	Less or low technical affinity, used to work with hardware	German
	Team Leader	Skilled workers to technician	As above	German
	Supervisor	As above	As above	German
	Launch team	As above	Middle to high technical affinity, uses software and hardware for his work	German, English
	Core team	As above	As above	As above
	Core team/ launch team manager	As above	As above	As above
	Manufacturing systems engineer	Engineer	High technical affinity, used to work with computers ‘naturally’	As above
	Manufacturing Systems Engineer Manager	Engineer	As above	As above
	System “Owner”	As above	As above	As above
VOLVO	Operators	Primary school/ high school/College	Differs depending on age, education & personal interest; no virtual simulations experience	Swedish, English
	Key Operator – Teacher	As above	As above	As above
	Key Operator – Hands On	As above	As above	As above
	Key Operator – Safety	As above	As above	As above
	Group Manager	As above	As above	As above
	Pilot Plant Team	As above	As above	As above
	Team Leader	As above	As above	As above
	Design engineer	≥College	Very good knowledge in computer and virtual simulations	As above
	Introduction Engineers	As above	Differs depending on age, education & personal interest; various virtual simulation skill levels	As above
	Production Engineers	As above	Good computer knowledge; different skill levels of virtual simulation depending on education	As above
	Technical Preparation Engineer	As above	As above	
	Virtual Manufacturing Engineer	As above	Very good knowledge in computer virtual simulation	As above

Appendix B – Stakeholders' roles, responsibilities and current involvement to training

	Position	**Roles & Responsibilities**	**Current involvement in training**
OPEL	Manufacturing Systems Engineer Manager	To manage the general assembly of a plant i.e. process planning & virtual engineering.	Coordinating manufacturing system engineers
	Manufacturing Systems Engineers	To design & produce assembly procedures.	Plan & decide assembly sequences
	Virtual Engineers	To prepare & alter virtual build (3D CAD data) when required.	Support planning & decision of assembly sequences
	System Owner	Responsible for the overall IT system & maintenance of database	Support & maintain IT system & database
	Launch Team Manager	To lead & coordinate launch team	Coordinating launch team
	Core Team Manager	To lead & coordinate core team	Coordinating core team
	Core Team	To optimise the assembly process in terms of cost, quality, time & efficiency at each plant.	Improving assembly sequence
	Launch Team	The Launch Team or Pilot Team is an ad-hoc team that is formed during a launch of a new product & is responsible to: i) provide feedback during virtual builds; ii) to assist physical build at the pilot line & provided feedback; iii) train Team Leaders & support them in training Operators when required.	Train Team Leaders at the early stage of product launching
	Supervisors	A Supervisor manages a group of team leaders & their operators (up to 6 team leaders & 30 operators).	Oversee training in his team
	Team Leaders	A Team Leader manages a group of up to six Operators for up to 4 stations & is responsible to: i) train & assist Operators when problems in assembly line occur/repairs are required; ii) perform assembly tasks when required (due to operator's illness, etc); iii) provide feedback regarding quality & performance to a Supervisor	Trainee during the early stage of product launching & trainer during the later stage of product launching
	Operators	To perform a set of assembly tasks in one or more workstations with a high quality in a given period of time. Job rotation is performed by assigning an Operator to	Trainee

		different work stations.	
VOLVO	Design Engineers	To design parts of new or modified products & develop assembly instructions	Supporting assembly sequence planning
	Production Engineers/Introduction Engineer	To create/modify paper-based assembly instruction when a new product is developed or changes in the plant occur (SPRINT) & identify best practices.	Planning & deciding assembly sequences
	Virtual Manufacturing Engineers	To manage, support & provide overview of ways to work with virtual systems.	N/A
	Technical Preparation Engineer	To coordinate & steer of all product changes to the manufacturing line.	Improving assembly sequence
	Team Leaders	A Team Leader manages a group of up to 4 stations (up to 6 Operators per work station). A Team Leader appoints a number of Operators in his team as Key Operators who will train operators in his team & reports any unresolved issues to the Group Manager who forwards the information to the Production Engineer.	Oversee training in his team
	Pilot Plant Team	To participate in virtual & physical builds & to provide training for operators from assembly line on a new/update vehicle built.	Train key operators at the early stage of product launching (at the pilot line)
	Operators/Key Operators	Operators: To perform a set of assembly tasks in one or more work stations with a high quality in a given period of time. There are up to 4 work cells in each work station. Job rotation is performed by assigning Operators to either different work stations or work cells. Key Operators: An experienced Operator that is appointed by a Team Leader to assume additional roles. There are three types of Key Operator : i) Teacher - train Operators in the main line; ii) Hand On - to resolve assembly problems at the Adjustment station; iii) Safety- to enforce safety within their team.	Key Operators – trainee at the pilot line & trainer at assembly line Operators - Trainee

Appendix C - Refined elicited user requirements for assembly tasks

Theme	Sub theme(s)	Stakeholders	Importance	Identified from
Key skills/ knowledge included	Assembly sequence, parts number and appearance, tools, end location of parts/tools, critical part of the assembly operations	OPEL-Team Leaders, Manufacturing System Engineers, Core Team; VOLVO- Production Engineers, Pilot Plant Team	High	Hierarchical Task Analysis
	Self-inspection of own work		Medium	Hierarchical Task Analysis
	How to read and understand SPRINT-for VOLVO		Medium	Hierarchical Task Analysis
	Cause and effect of assembly operation		Medium	Hierarchical Task Analysis
	Start locations of parts/tools		High	Hierarchical Task Analysis
	Tool and lifting device handling		Medium	Hierarchical Task Analysis
Performance measures	Cost and time to execute training	All	High	Thematic Analysis
	Quality (number of correct assembly sequence)		High	Thematic Analysis
	Time (performing correct sequence within the time given)		High	Thematic Analysis

Appendix D – Suggested potentially beneficial or worthy investigation features for virtual training

Theme	Sub theme(s)	Stakeholders	Importance	Feasibility	Identified from
Capture and Feedback of assembly issues	Yes	All	High	High	Link Analysis
	Should also be used to capture knowledge/experience of Operators		Medium	High	Link Analysis
Relationship with existing IT system	Should allow linkage to enterprise data of the existing IT system	All, except Team Leaders & Operators	High	High	Thematic analysis
User Interface	Easy to use	All	High	High	Thematic Analysis
	No additional training is required		High	High	
Access to the system	Local (Operators: main line)	Team Leaders, Operators	High	High	Thematic Analysis

Game like approach	Yes	All	High	High	Thematic Analysis
Relationship with current training on pre-series vehicle	Used in conjunction with training on pre-series vehicle (for new product)	All	High	High	Timeline Analysis
	Used to train new variants or modification of existing products without pre-series vehicle		High	High	Timeline Analysis
High realism	Simulate parts behaviour for flexible parts e.g. wiring	OPEL (System Owner, Manufacturing System Engineers, Design Engineers, Virtual Engineers, Launch Team, Core Team), VOLVO (Virtual Manufacturing Engineers, Production Engineers, Design Engineers, Pilot Plant Team)	High	High	Thematic Analysis
	Simulate assembly process in different workstations or work cells		High	High	Thematic Analysis, Hierarchical Task Analysis
	Simulate appearance of parts		High	High	Thematic Analysis
	Simulate multiple Operators (up to 2-6 Operators)- for VOLVO		High	Medium	Hierarchical Task Analysis
	Simulate tolerances		Medium (VOLVO), Low (OPEL)	Low	Thematic Analysis
	Simulate effect of weight and centre of gravity		High	Very low	Thematic Analysis
	Simulate force feedback		High	Very low	Thematic Analysis
	Accommodate “feel” of the part		High	Very low	Thematic Analysis
	Simulate time pressure on the main line (OPEL)	Team Leaders, Operators	High	High	Thematic Analysis
	Simulate moving assembly line during assembly operations (OPEL)		Medium (OPEL), Low (VOLVO)	Low	Thematic Analysis