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APPLICATION OF MOKA METHODOLOGY TO CAPTURE KNOWLEDGE IN DESIGN FOR POKA-YOKE ASSEMBLY

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ABSTRACT
Design For Poka Yoke Assembly-DFPYA is a new DFX created to prevent potential assembly issues since early design stages. This prevention is possible by designing the product with poka-yoke or error-proofing characteristics. DFPYA guide designers to make decisions based on poka-yoke assembly design requirements. As results of the application of these requirements designers are able to create solutions to prevent assembly issues for the specific product in development. This paper proposes the application of MOKA methodology to capture, organize and storage the poka-yoke designs that are created in a specific Company in order to reuse this knowledge in future new product development projects.

Keywords: knowledge management, poka-yoke, error-proofing, assembly, DFX, design process

1 INTRODUCTION
Assembly failures can be solved in different ways; based on experience from experts it is noted that better actions to eliminate failures are redesigning the product by applying poka-yoke principles [1]. Poka-yoke is a Japanese word that means error-proofing. Poka-yoke philosophy works based on primarily two principles: designing a process or product in a way that a defect cannot be make and designing a product or process so if a defect happen, it is obvious and can be immediately corrected [2]. There are many examples of poka-yoke redesigns that prove the effectiveness to eliminate failures or defects to zero [1, 2, 3,4]. The challenge of DFPYA is to apply the philosophy of poka-yoke since task clarification stage in order to be more efficient during new product development projects.
Design For Poka Yoke Assembly is a new DFX that guide designers since task clarification stage to orient product development to prevent potential assembly issues by adding poka-yoke features to product design this practice aid to minimize redesigns that are commonly performed in later stages after product development [3, 4, 5].
This research continues the work realized in [3,4,5,6] about DFPYA, the purpose of this paper is to use MOKA methodology to capture, organize and storage the poka-yoke designs that are created in a specific Company in order to reuse this knowledge in future new product development projects.
The ICARE forms (Illustrations, Constraints, Activities, Rules and Entities), used in the informal model for MOKA knowledge representation [7] were adapted in order to use them to capture the needs of knowledge related to DFPYA. A programme was created using MS Access software® [8] to facilitate the implementation of DFPYA in industry. A case study was realized to implement this programme in a Company the develop and manufacture mechanical and electromechanical products, the case study consisted in capturing knowledge related to assembly issues and redesigns that were developed, in different products by manufacturing and application engineers, to solve these issues in a poka-yoke way.

2 MOKA METHODOLOGY
MOKA means methodology and tools oriented to knowledge based engineering-KBE applications. MOKA aims to reduce the cost of building and maintaining KBE applications through efficiency.
The three elements of MOKA are: i) description of the lifecycle for a KBE, ii) representation of knowledge associated with the application using text and graphics and iii) software tool that helps to apply the representation and the route map [7].

ICARE forms (Illustration, Constraint, Activity, Rule and Entity) provide a method for standardized storage of knowledge, links to maintain the 'design story' and reference back to the raw knowledge. The MOKA informal model of knowledge representation will be used in this approach as method to capture company experiences developed by designers and engineers to eliminate the occurrence of assembly issues.
In formal model the purpose is to provide a rigorous model of the application knowledge. The formal model provides the potential for automatic transfer to the KBE platform. Although the MOKA models are deliberately intended to be neutral, the meta-models have been designed with typical KBE architectures in mind [7, 9].
The informal model is used in this work to capture the knowledge that is generated in a Company in order to reuse the poka-yoke ideas previously developed by engineers; and facilitate the design process when designers during conceptual, embodiment and details design stages are thinking in poka-yoke solutions to prevent potential assembly issues for new product development projects.

2.1 ICARE Forms

In the informal model of MOKA knowledge representation is classified in five types:

i) Illustrations: for recording past experience, case histories, anecdotal knowledge.
ii) Constraints: restrictions on the objects or the attributes of an object.
iii) Activities: the elements of the design process.
iv) Rules: knowledge that directs choices in the activities.
v) Entities: the objects that describe the product.

ICARE forms helps to store knowledge in a standardized form. The first level of representation is the Informal Model, which is largely composed of linked forms. The ICARE forms are useful to provide a framework in which to store the units of knowledge and a template so that each time a piece of knowledge is described it is done in a similar way.
Each ICARE form has a distinct template. The templates are separated by fields for recording the specific parts of the associated knowledge unit [7]; in order to capture DFPYA knowledge in these ICARE forms, some changes are proposed to adapt the templates for DFPYA purposes.
In table 1 is described the knowledge that is generated when developing a poka-yoke design solution and also is indicated the most appropriate ICARE form that can be used to capture that knowledge.

Table 1. DFPYA knowledge and corresponding ICARE forms to capture this knowledge

DFPYA knowledge	ICARE form proposed to capture DFPYA knowledge
Basic functions involved in the poka-yoke solution	Entity form, Functional
Principles and technical solutions	Entity form, Functional
Steps or activities that must be followed to design the solution	Activity form
Design poka-yoke rules that can be established for future new product development projects	Rule form
Constraints to implement poka-yoke design solution	Constraint form
Illustrations showing poka-yoke design features	Illustration form

An example of ICARE form adapted for DFPYA knowledge is showed in figure 1. This figure indicates the fields that were modified for this application. An arrow "→" is showed to indicate a new field added for DFPYA purposes and asterisk "*" is used to indicate a definition of a specific field that was adapted to capture DFPYA knowledge.

3 DESIGN FOR POKA-YOKE ASSEMBLY-DFPYA

DFPYA defines five clusters these are:
Dx-Design stages cluster: this cluster has three elements corresponding to the design stages i) conceptual-D_1, ii) embodiment-D_2, iii) details design-D_3.
Tx-Type of design decisions cluster: there are six elements in this cluster and correspond to decisions that are made by designers during design process, these are: i) product architecture definition-T_1, ii)

type of material selection-T_2, iii) part features design-T_3, iv) fastening method selection-T_4, v) tolerance allocation-T_5, vi) assembly sequence definition-T_6.

MOKA ICARE FORMS:		ENTITY	
Name	*	Entity or mechanism in the product that experience the assembly issue.	
Reference		Reference of described entity (used as a link from other ICARE forms and a link to the charts)	
Entity type		Functional E-form	
Functions		Names and references of key functions associated with the poka-yoke functional Entity.	
Behaviour	*	Names and references of key aspects of behaviour associated with the poka-yoke functional Entity.	
Context, information validity		Short text to explain the circumstances when this knowledge can be applied and any assumptions made about boundary conditions for the application.	
Description	*	Description of the functions where is developed the poka-yoke solution. Description of any decomposition into sub-functions or solutions of poka-yoke design developed. Options for poka-yoke solutions or conceptual structures and criteria for selection.	
➡ DFPYA clusters	*	Corresponding DFPYA clusters applicable to the poka-yoke solution developed. Ax, Sx, Rx, Tx, Dx.	
Related Activities		List of activities where the described entity is involved (used as a link to the process chart and Activity form)	
Related Entities		Parent	Entity that is the parent of the current entity
		Child	Entity that is a child of the current entity
		Undefined	Any other related entity
Related Constraints	*	List of poka-yoke constraints that are associated with the described entity (used as a link to Constraints forms)	
Related Rules	*	List of poka-yoke rules that link two or more entities (used as a link to Rule forms)	
Related Illustrations	*	List of cases illustrating poka-yoke design solutions	
Part numbers	*	Company part numbers of components involved in the poka-yoke solution.	
Information Origin		Reference to the associated raw knowledge (used as a link-external to the MOKA tool - to the raw knowledge in the knowledge repository.	
Management		Author	Author of the form
		Date	Date of last modification
		Version Number	Version number of the form
		Status	Status (completeness, linked condition, verification)

➡ New field added for DFPYA purposes | * Definition adapted for DFPYA purposes

Figure 1. Functional E-form from MOKA methodology [7] adapted to capture knowledge related to poka-yoke design solutions

Sx-System phases cluster: this cluster has four elements, i) system production-S_1, ii) system installation-S_2, iii) system operation-S_3, iv) system replacement-S_4.
Ax-Assembly issues cluster: the elements of this cluster correspond to the sixteen assembly issues defined in previous papers [3,4] such as product damaged-A_1, Difficult to align parts-A_2, instability in dynamic parts-A_3, incorrect position of parts-A_4, wrong part assembled-A_5, omission of parts during assembly-A_6. See complete list in [3, 6].
Rx-Poka-yoke assembly design requirements cluster: in this cluster are included the seventeen requirements developed in previous works that states how must be designed a product to prevent specific assembly issues. The elements for this cluster are described in [3]. Examples for some Rx are: R_1: "Conceptualize a product architecture focused to bring interfaces in modules that have to be inspected and tested during assembly operations", R_2: "Easy and safety for the user to change those modules that have to be disassembled and assembled to change product configuration and give maintenance to product".

3.1 MOKA methodology to capture DFPYA knowledge in Industry

As mentioned in section 2, MOKA methodology is used to represent DFPYA knowledge that is generated in industries in order to reuse it for new product development projects. The steps that were proposed to implement MOKA methodology are described in figure 2. This process starts when Company receive claims about assembly issues, these claims can be from system production, installation, operation or replacement phases. After a claim is received the assembly issue is captured in an ICARE form, for this application is the E-form, this knowledge is storage in a database (see section 4). The next step is to analyze the assembly issue in order to develop a poka-yoke solution. The poka-yoke solution process consists in search into solutions database, previously captured, and if solution is not found then a new design solution is developed for that specific case, this solution is developed by following the methodology of DFPYA [3,4,5,6] and it is captured in the corresponding ICARE form based on table 1. If solution already exists in database (see section 4) then this solution is used to solve the specific assembly issue.

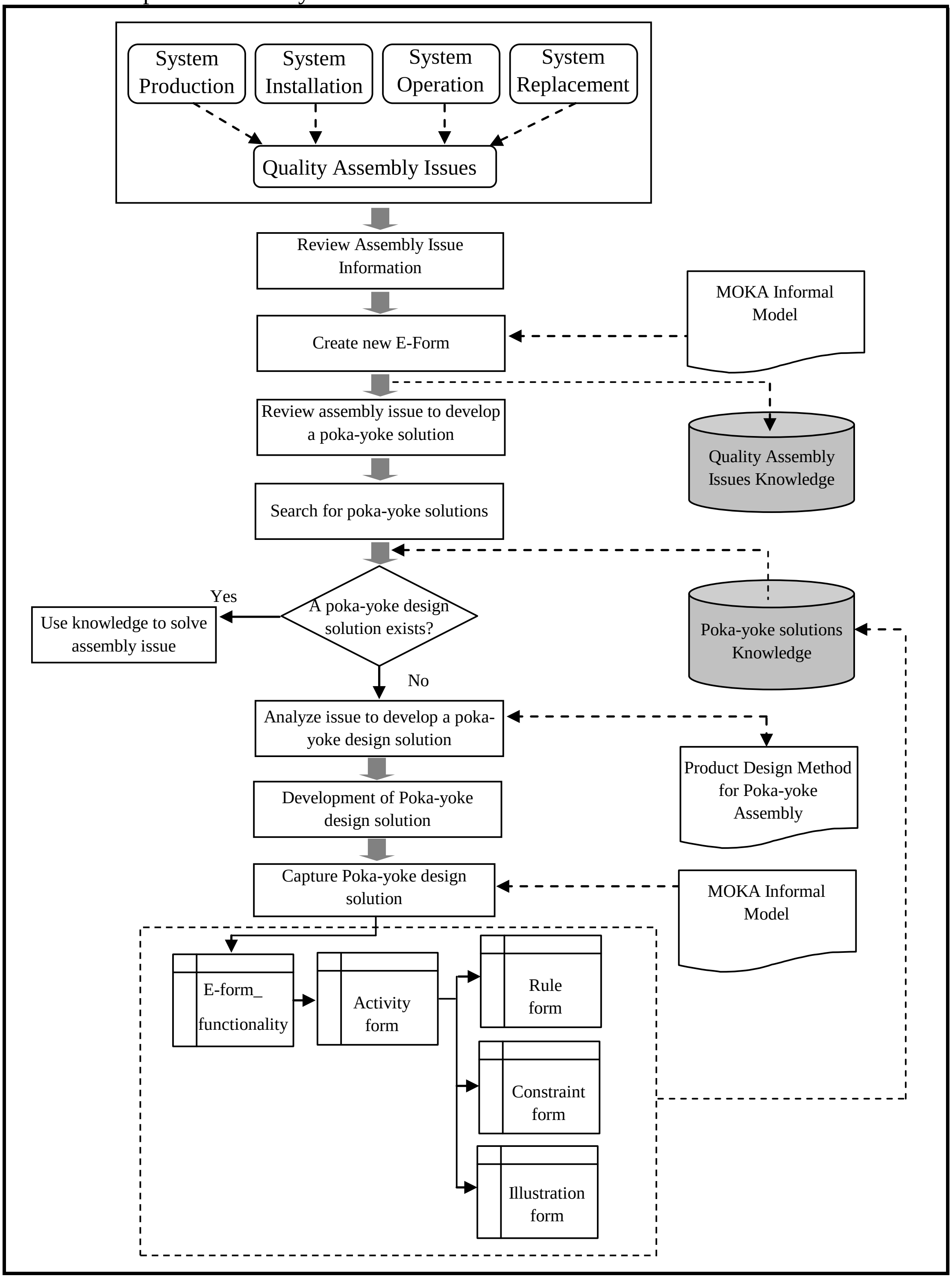


Figure 2. Diagram to describe the steps to represent knowledge in Industry using MOKA methodology in the informal model

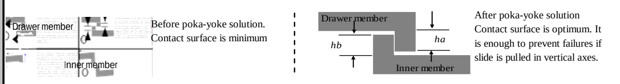
MOKA ICARE FORMS:	ENTITY	
Name	Stop inner-drawer	
Reference	PY_SID_001	
Entity type	Functional E-form	
Functions	Stop function located in the inner and drawer.	
Behaviour	Failure AX_SID_001: it happen when slide is pulled in horizontal and then vertical axes it cause drawer did not stop in inner.	
Context, information validity	This knowledge can be applied when designers are developing the type of mechanism the will keep together the inner member and outer member. Slides must have a stop mechanism to prevent slide members get disassembled causing a failure. This poka-yoke solution shows the importance of allocate tolerances; during application of slides when the final user pull the slide, even the application is to move in horizontal way there is always a gap between components that allow final user to move the slide in vertical way; if this happen it can cause a failure due to inner and drawer get disassembled. It was found that an optimum tolerance can be allocated to make product robust to prevent this issue.	
Description	The poka-yoke solution consists in increase the contact surface between inner and drawer member. The contact surface between these members can be increased by increasing the height ha of drawer member and height hb of inner member. See picture.  	
DFPYA clusters	S_3, A_{13}, R_{16}, T_5, D_3	
Related Activities	List of activities where the described entity is involved (used as a link to the process chart and Activity form)	
Related Entities	**Parent**	Entity that is the parent of the current entity
	Child	Entity that is a child of the current entity
	Undefined	Any other related entity
Related Constraints	CT_SID_001	
Related Rules	RL_SID_001	
Related Illustrations	ILL_SID_001	
Part numbers	SN8987-CH (slide) 4180-0450-CE (drawer member) 4180-5980-CE (inner member)	
Information Origin	FIS#3456-01 (customer complaint), ECR#2345-003 (engineering change request)	
Management	Author	G. Estrada
	Date	05/12/2009
	Version Number	A
	Status	Done

Figure 3. Example of poka-yoke solution developed in Industry to prevent an assembly

Figure 3 shows and example of ICARE form (using a template in excel) to capture a poka-yoke redesign developed in a Company that develops and manufactures mechanical and electromechanical products. See figures 6 and 7, these figures show this example from figure 3 but captured in the DFPYA software.

4 DFPYA SOFTWARE

In order to facilitate the use of DFPYA methodology it was programmed in MS Access software [8] a programme to guide designers during design process. There are two options in this program: i) ‘DFPYA New Product’ and ii) ‘DFPYA product redesign’ (see figure 4, step 1). ICARE forms are captured in DFPYA knowledge management then based on this knowledge captured; designers can access to DFPYA product redesign and select which specific assembly issues they desire to prevent in a product. The option ‘DFPYA new product’ was designed to be used since task clarification stage; this option starts asking several questions to designers in order to identify potential assembly issues that can occurs in the new product being developed; after response questions the DFPYA matrix is automatically generated [5,6]; also in this section of the program is automatically separated the applicable Rx for each design stage: conceptual, embodiment and detail design; designers can easily select in each stage the applicable requirements and see the knowledge, previously captured in option “DFPYA product redesign”, and review examples of poka-yoke redesigns that were developed to prevent a specific assembly issue by applying a poka-yoke assembly design requirement.

The first step to start capturing knowledge is to make click in option ‘DFPYA product redesign’, see figure 4. Then a new window appears ‘DFPYA PRODUCT REDESIGN’ where two options are available for users. The first button ‘Direct Rx capture’ is to capture knowledge that corresponds to specific poka-yoke assembly design requirement (see figure 4, step 2). It means that poka-yoke solution is reviewed to identify which Rx corresponds based on the type of principle used (see figure 4, step 3). Then in the step 4 the option used is ‘ICARE form’ (see figure 4, step 4) in order to visualize the window to capture the ICARE form. After make click in ‘ICARE form’ button a question is asked to capture new assembly issues, it means that designers before capture a poka-yoke solution they must create the specific assembly issue that is solved with that solution (see figure 5).

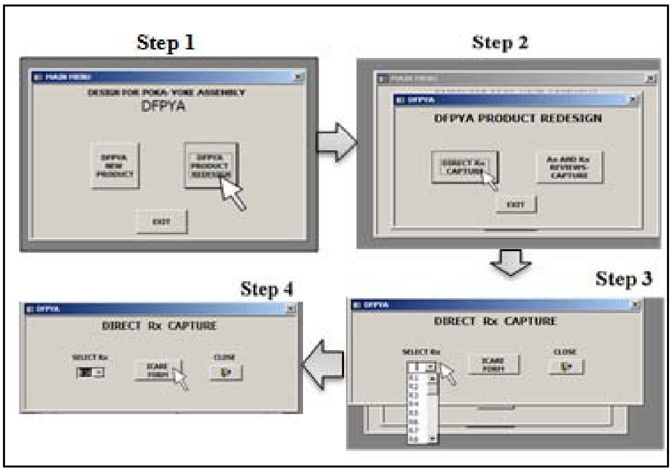


Figure 4. Step 2, 3 and 4 to capture DFPYA knowledge

Figure 5. Step 5 and 6, windows to capture assembly issues.

If question is answered as yes a new window appears ‘creating a form’ in this window is asked this question: Type of ICARE form? In this case will be captured the assembly issue and the type of ICARE form to capture Ax is the form ‘Entity-Behavioural’; see step 6 in figure 5.

After select the type of entity to capture the Ax it appears a new window with the structure of this entity, see figure 6. The image showed in figure 6 includes data but after step 6 when a click is performed in ‘Entity (Behavioural)’ option the window shows an empty form which is ready to capture new data.

5 CASE STUDY

The case study was realized to implement the DFPYA software in a Company. This case study consists in a research performed in a Company that develops and manufactures mechanical and electromechanical products, the purpose was to identify assembly issues occurred in products and corresponding poka-yoke redesigns developed in this Company to solve these issues in order to capture knowledge in the DFPYA programme described in section 4. In figure 6 is showed an example of Ax (A_{13}- Operation assembly failures) that was captured in the entity-behavioural form.

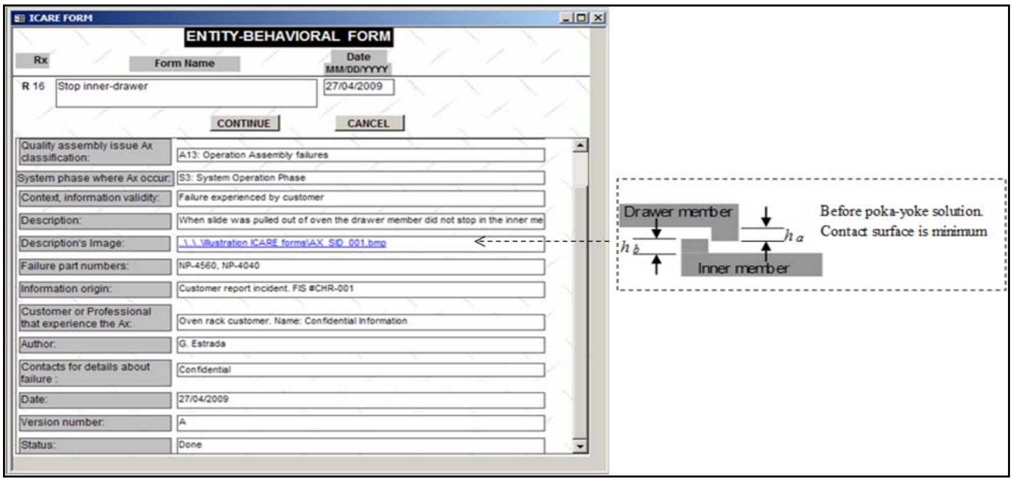


Figure 6. Example of entity-behavioural form to capture Ax knowledge in a Company

In the field 'Description image' is inserted the hyperlink to the image that explains the corresponding assembly issue, in this case is A_{13}.
To capture the poke-yoke solution developed for A_{13} described in figure 6 can be followed same steps from 1 to 7 the only difference is in step 6 will be selected the option 'Entity-Functional form'; the window to capture poka-yoke solution in a functional entity, example is showed in figure 7.

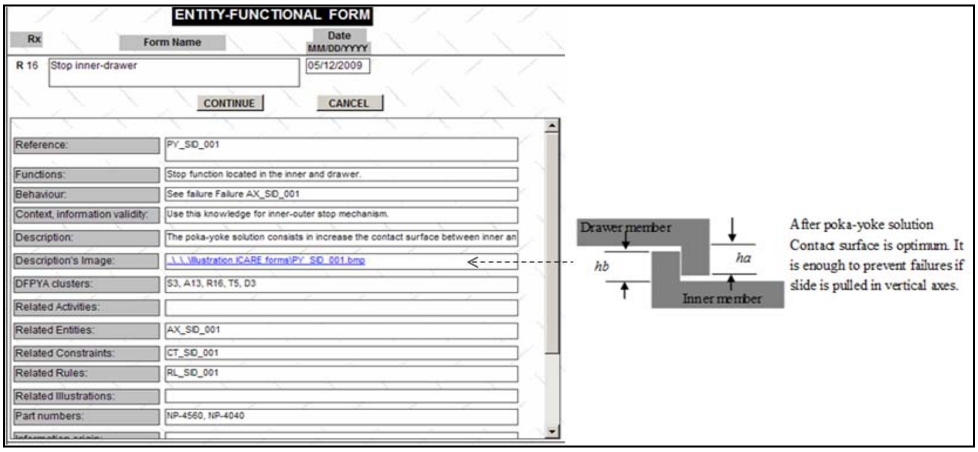


*Figure 7. Example of poka-yoke solution captured in "Entity-Functional Form" to prev*ent Ax showed in figure 8.

Another example of knowledge identified during the case study is showed in figure 8. A poka-yoke redesign was developed and based on 'DFPYA requirements-Rx cluster' this solution correspond to requirement R_9 *(this requirement states: "To parts that will be assembled by manual methods use fastening methods that can be easily inserted in order to avoid damages and excessive fatigue to assembly operators")* R_9 helps to prevent assembly issues A_1-*Product damaged* and A_8-*Ergonomic issues to assembly parts* and A_{12}-Damages of parts during installation.

5.1 Application of DFPYA software during new product development

As part of this case study a new product development project was selected to apply DFPYA software. The purpose of apply DFPYA software in this new project was to identify in early design stages potential assembly issues in order to develop poka-yoke solutions, the development of these solutions was possible considering poka-yoke assembly design requirements and knowledge captured from previous projects (such as ICARE forms showed in figures 6, 7 and 8).
The first step was to generate the DFPYA matrix (see details of this process in [5,6]), then the corresponding poka-yoke assembly design requirements were reviewed, the revision for these requirements were realized during each design stage. The DFPYA software has an option to review them during each stage.

During conceptual design, designers identified 2 potential assembly issues, both associated to A_{10}-difficult to realize inspection and test. As part of embodiment design phase designers identify that new product design was associated to 7 potential assembly issues, these are A_4, 2 of A_5, A_8, A_{11}, 2 of A_{10}. When designers reviewed the detailed design of new product identified 1 potential assembly issue related to A_8. DFPYA software allows designers to review previous ICARE forms captured (such as example from figure 6) about Ax, it helps designers to give an idea which specific components and features represent a potential assembly issue. In total 10 potential assembly issues were identified. In section 5.2 is showed an example of poka-yoke feature added to prevent an assembly issue identified during embodiment design phase.

5.2 Results: poka-yoke features added to prevent assembly issues

After assembly issues are identified the DFPYA software help designers to review the corresponding poka-yoke assembly design requirements that are connected to the specific Ax being reviewed and also the DFPYA databases are linked to Rx in a way that designers are able to review the ICARE forms previously captured. For example during embodiment design stage the DFPYA software indicates that product design is potential to present the assembly issue A_8, then designers reviewed the components of embodiment design and based on detail analysis for each component and previous knowledge captured in ICARE form they identified a potential assembly issue A_8 in a 'cover plastic component'. The example of ICARE form that helped designers to think how the A_8 can happen in the 'cover plastic component' (from new design) is showed in figure 8 that explains how a 'setter plastic component' (from old product, previously captured in DFPYA database) can causes an ergonomic issue (A_8) due to it is manually inserted during assembly operation and poka-yoke solution, developed for that specific case occurred in the old product, was to reduce the height of the lock, then designers based on the requirement R_9 (R_9 states: *"To parts that will be assembled by manual methods use fastening methods that can be easily inserted in order to avoid damages and excessive fatigue to assembly operators"*) that is associated to A_8 and reviewing the poka-yoke solution showed in figure 8 they also reduce the dimension of the thickness in the 'cover plastic component' as was realized in the 'setter plastic component' when height of lock was decreased. This early modification in the product design helped to prevent an assembly issue. See figure 9.

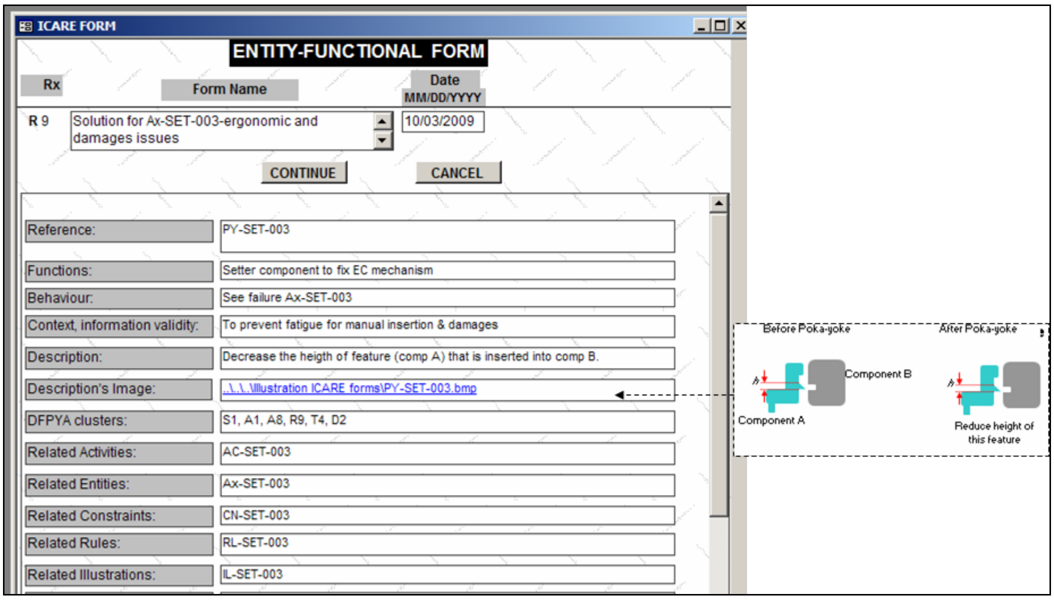


Figure 8. Example of Entity-functional form to capture poka-yoke solution using R_9 to eliminate A_1 and A_8 related to damages and ergonomic issues to insert setter component.

6 CONCLUSIONS AND FUTURE WORK

The use of MOKA methodology helps to capture and storage important knowledge that is generated by designers and manufacturing engineers during the process of developing solutions to fix failures or defects occurred in products.

DFPYA is focused in those issues related to assembly aspects that could be presented in the life system phases such as production, installation, operation and replacement. The ICARE forms proposed in the informal model by MOKA methodology are useful as first approach to capture this knowledge in order to facilitate the process to create poka-yoke solutions to designers when developing new products. The case study demonstrates that assembly issues can be early detected and poka-yoke solutions can be developed before product start mass production.

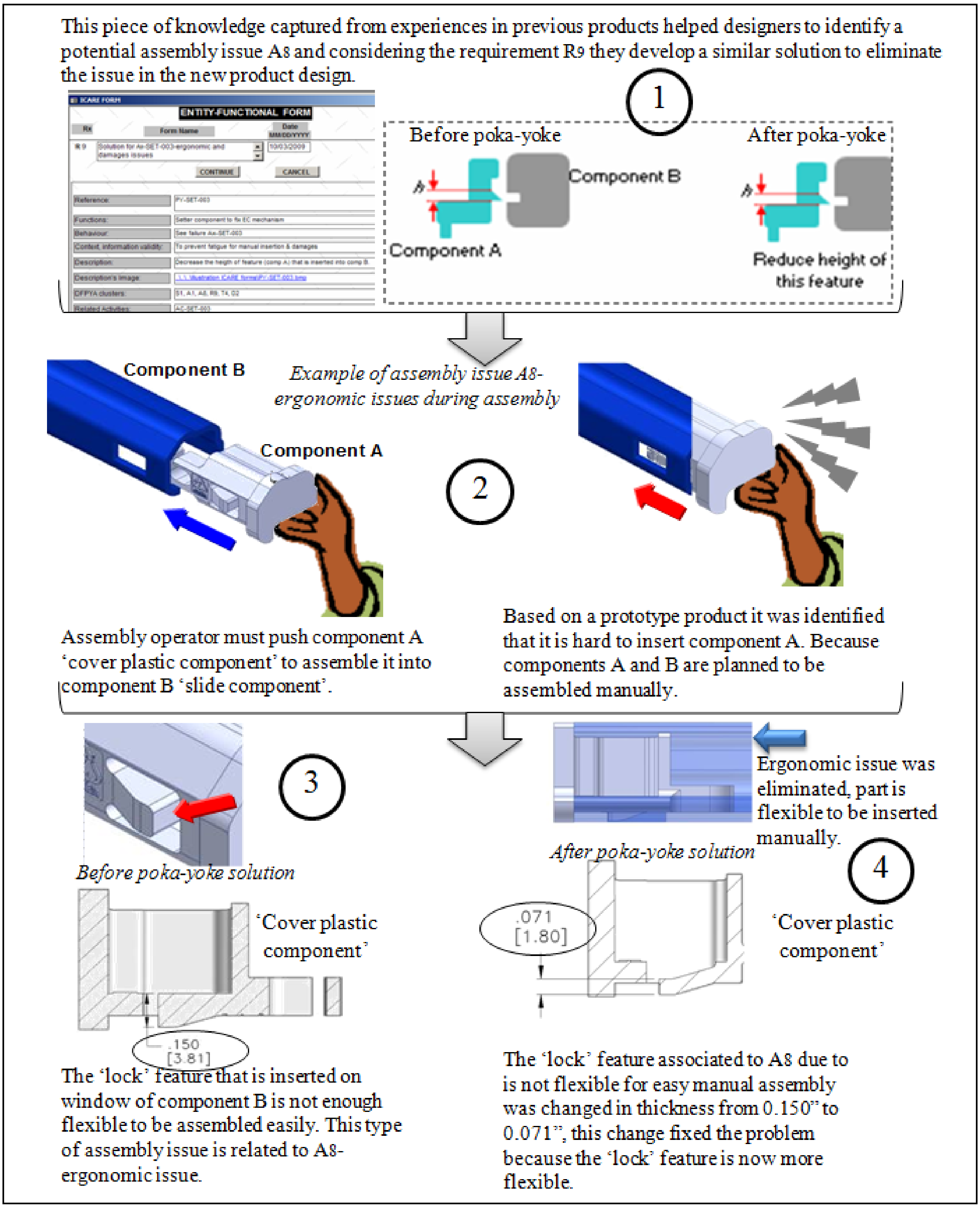


Figure 9. Example of assembly issue A_8 detected during embodiment design stage and poka-yoke solution developed to prevent it based on R_9.

For example in figure 9 is showed a plastic part that was changed in a dimension to prevent an assembly issue, this early modification was realized before the injection mold was created to fabricate this component. The anticipation of this problem saves time and money associated when mold has to be corrected to fit a new dimension of the component changed.

The DFPYA programme is also useful as training for those designers that do not have a lot of experience working in that type of products. Future work in this area will be to apply the formal model of MOKA methodology to design process using KBE systems oriented to Design For Poka-Yoke Assembly. Another activity that will be performed to demonstrate how DFPYA helps to develop more efficient products is to apply DFPYA programme in different industries.

REFERENCES

[1] Shimbun, N.K., *Poka-yoke: Improving Product Quality by Preventing Defects*, 1988 (Productivity Press Inc., Portland).

[2] Shingo, S., *Zero Quality Control: Source Inspection and the Poka-yoke System*, 1990 (*Productivity Press, Portland).*

[3] Estrada, G., Riba, C. and Lloveras, J., An approach to avoid quality assembly issues since product design stage, *International Conference on Engineering Design,2007, ICED'07*.

[4] Estrada, G., Lloveras, J. and Riba, C., Design For Poka Yoke Assembly an approach to prevent assembly issues, *International Design Conference, Design 2008*.

[5] Estrada, G. and Lloveras, J., Prioritization of product requirements to Design For a Poka-Yoke Assembly-DFPYA. International *Conference of Engineering Design (ICED'09)*, Vol DS58-7. Ed: Design Society. 24-27 August, Stanford University, Stanford, California, USA, pp. 333-44.

[6] Estrada, G., Lloveras, J., A method to complement product requirements list to Design for a Poka-Yoke Assembly-DFPYA. *Proceedings of International Conference on Research into Design, ICoRD'09*. Ed. Amaresh Chakrabarti. Ed. Research Publishing Services, Singapore. Indian Institute of Science, Bangalore, India, 7-9 January 09, pp. 136-43.

[7] Stokes, M., Managing Engineering Knowledge, *MOKA: Methodology for Knowledge Based Engineering Applications*, 2001 (ASME Press, New York).

[8] Microsoft ® Access 2002 (10.2627.2625).

[9] Skarka, W., Application of MOKA methodology in generative model creation using CATIA, 2007, *Engineering Applications of Artificial Intelligence* 20 pp 677-690.

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Gabriela is Professor-Researcher of Industrial Engineering Department at CETYS University. She teaches quality engineering and manufacturing processes. She has 10 years experience working as Senior Quality Engineer in aerospace and automotive industries. She has participated in new product development projects to assure product quality by orienting product and process to error-proofing philosophy. She is interested in researches about knowledge management and KBS to systematize product and process designs by applying error proofing or poka-yoke philosophy since early product and processes design stages, in order to eliminate defective parts and failures commonly presented in mechanical and electromechanical products during life phases of a system such as production, installation, operation and replacement phases.