



# Study for Next technologies

## Decorations for Plastic & Stainless Steel Substrates

- 1. Introduction ..... 2
- 2. Scope ..... 2
- 3. Forecasting question ..... 3
- 4. FORMAT methodology ..... 4
- 5. Sources of information and data ..... 7
- 6. Process description ..... 9
- 7. Alternative technologies ..... 15
- 8. Major problems and limiting resources ..... 20
- 9. Patterns of evolution ..... 23
- 10. Results of data analysis ..... 28
- 11. Future of decoration technology ..... 30
- 12. Working team ..... 34
- 13. Appendix ..... 35

## 1. INTRODUCTION

1.1. This document provides a description of results of work performed in border of Pilot 2 case study. Pilot 2 is a second application of FORMAT methodology to the case study provided by Whirlpool Europe<sup>1</sup>. FORMAT methodology is being applied in rounds of 12 sessions. This document is a report from the second round performed from September 11, 2014 (session 2.1) till December 4, 2014 (session 2.12).

1.2. Case study provided by Whirlpool concerns future technologies of decorations on plastics and stainless steel substrates. Key-elements of decoration technologies, their evolution and features of forthcoming decoration technologies, presented in this report, should be reviewed by any team developing a project on decoration technologies to be applied at Whirlpool.

## 2. SCOPE

2.1. The scope of this report covers application of FORMAT methodology to a case study provided by Whirlpool. Selected alternative decoration technologies have been studied in order to describe partial functions common across different technologies. Decoration technologies have been investigated to identify problems, patterns of evolution and measures describing development of decoration technologies. Entire study has been performed with limitation to decoration on plastics and stainless steel that should be applicable in Whirlpool Europe factories. Whirlpool signaled a particular interest in following technologies: ink-jet printing, laser marking. Results of a forecasting study describe a future decoration technology, not by providing its name, but by providing a list of features that a future decoration technology or family of technologies should assure.

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<sup>1</sup> When Whirlpool Europe is a part of Whirlpool EMEA.

### 3. FORECASTING QUESTION

3.1. The most important question that should be answered:

Which is the **most promising decoration technology** for achieving present and future product need in coming 5 to 10 years at Whirlpool Europe factories?

It was asked to describe those future technologies (quality, flexibility, cost effectiveness) in details for **plastic and stainless steel** substrates in context of the following products:

- refrigerators,
- ovens,
- microwave ovens,
- dishwashers,
- washing machines,
- dryers,
- cooktops.

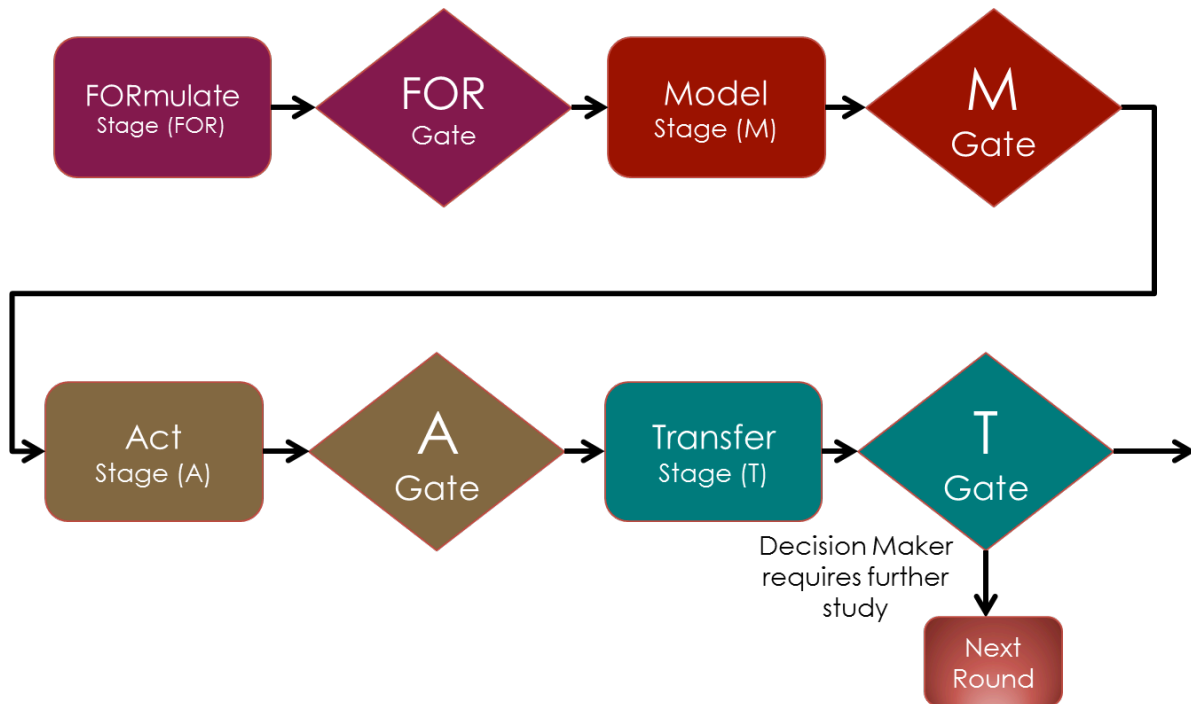
3.2. The second question which was formulated for this study:

*Which will be the expected (estimated) evolution of Main Parameters of INK-JET and LASER MARKING in coming 5 to 10 years at Whirlpool Europe factories?*

3.3. Two sub-questions were formulated as complementary:

- When will Ink-jet technology be ready to substitute silk screening and pad printing for domestic appliances (for plastic and stainless steel substrates)?
- When will a Laser Marking be completely able to produce colored marks in plastic?

### 4. FORMAT METHODOLOGY



#### 4.1. STAGE-GATE PROCESS

The FORMAT methodology has been conceived as a Stage-Gate process in order to keep control over project activities with the ultimate goal of maximizing the process efficiency in terms of ratio between the forecasting project outcomes and the efforts dedicated to produce them.

Stage	Main Functions	Duties
FOR: Diagnose duties and plan project	<prepare & make> <decision> <about forecasting project>  <define> <boundaries / resource> <of forecasting project>	<ul style="list-style-type: none"> <li>• WHY do we need to know the future?</li> <li>• WHAT do we need to know about the future?</li> <li>• HOW do we plan to learn about future?</li> </ul>
M: Define the system for forecast and study contexts	<review> <existing knowledge> <about system>	<ul style="list-style-type: none"> <li>• WHAT The System To Forecast (STF) is for? (WHY we need the STF?)</li> <li>• WHICH Systems allow to get the same results?</li> <li>• HOW to measure the STF and its alternatives?</li> <li>• WHAT the STF and its main alternative(s) are, were and are expected to be?</li> </ul>

<p>A: Develop forecast for defined system and context</p>	<p>&lt;identify&gt; &lt;a system of problems&gt; &lt;that drives evolution of system&gt;</p> <p>&lt;recognize&gt; &lt;evolutionary trends&gt; &lt;for identified system&gt;</p> <p>&lt;identify&gt; &lt;changes of performance characteristic in time&gt;</p> <p>&lt;aggregate and validate&gt; &lt;results of qualitative and quantitative studies&gt; &lt;into forecast&gt;</p>	<ul style="list-style-type: none"> <li>• Extract limiting resources from problems of STF;</li> <li>• Define set of solutions addressing limiting resources;</li> <li>• Fit data-series about parameters measuring;</li> <li>• Build conclusions about future traits for STF.</li> </ul>
<p>T: Prepare report and present results</p>	<p>&lt;transfer&gt; &lt;results of study&gt; &lt;to decision makers&gt;</p>	<ul style="list-style-type: none"> <li>• Transfer the forecasting results to beneficiaries/decision makers.</li> </ul>

## 4.2. STAGE FOR

Firstly, Stage FOR is related with the motivation of the forecasting analysis. This stage has to check whether the forecast is really needed or not. Moreover, at this stage the analysts needs to agree on:

- a. the description of the main objectives and the expected outputs of the forecasting project;
- b. a clear statement about how the forecast will be applied within the decision making process;
- c. the possibility to satisfy the formulated needs with or without forecasting.

Additionally, the resources to address the forecasting project have to be defined and the activities suitably planned.

## 4.3. STAGE M

Stage M is about the definition of boundaries for the forecast and the analysis of the relevant existing knowledge about the technology or system under study. In order to address this review, the analysts have to produce:

- a. an AS-IS description of the technology and its context;
- b. a list of resources relevant for the technology;
- c. a description of alternative technologies (a set of) that deliver the same results. This stage should result in a complete overview of the technology and the contexts it operates in.

## 4.4. STAGE A

The activities of Stage A consider both a qualitative and a quantitative perspective to forecast the future. The qualitative approach is further detailed into a problem- and a solution-focused generation of knowledge about future. The former defines critical problems and resources that limit the technological development (e.g. by using the TRIZ concepts of contradictions and resources). The latter aims at envisioning by analogical reasoning the potential evolutions addressing both the identified problems and the lack of system resources. The quantitative approach is based on data-series analysis (e.g. by applying regression analysis as logistic growth curve).

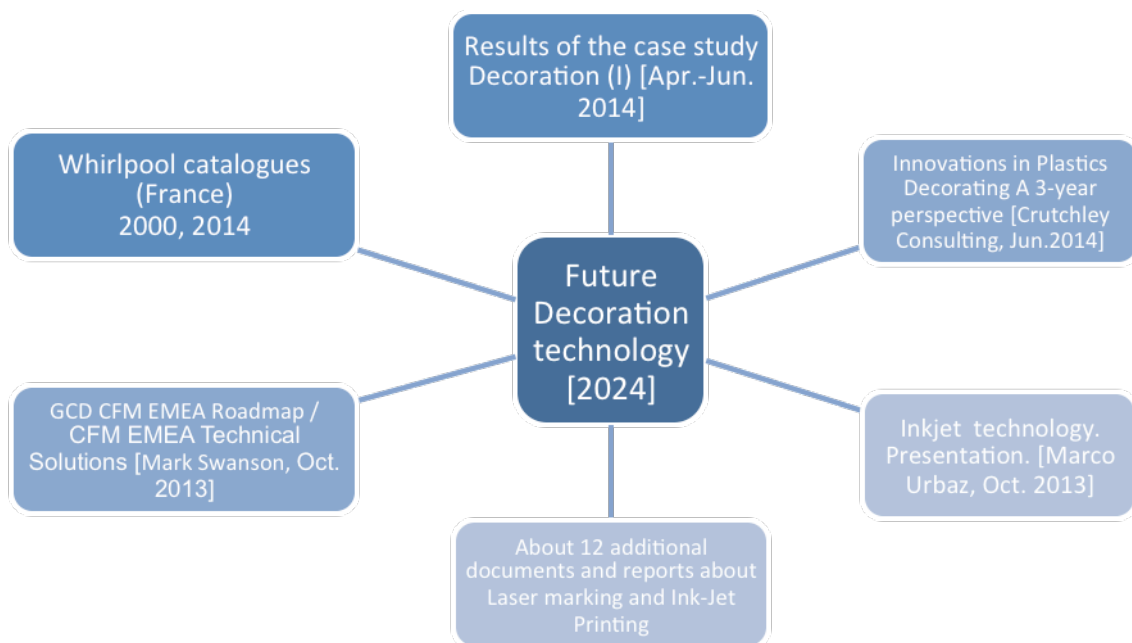
## **4.5. STAGE T**

Eventually, the T stage aims at transferring the forecasting results to the project beneficiaries. The analysts have to develop a proper knowledge flow system in order to transfer their results to beneficiaries, such as a reports, presentations, lists, posters, etc. The T stage has the role to provide significant contents and solid arguments in a concise form.

## 5. SOURCES OF INFORMATION AND DATA

### 5.1. THE FOLLOWING DOCUMENTS WERE USED

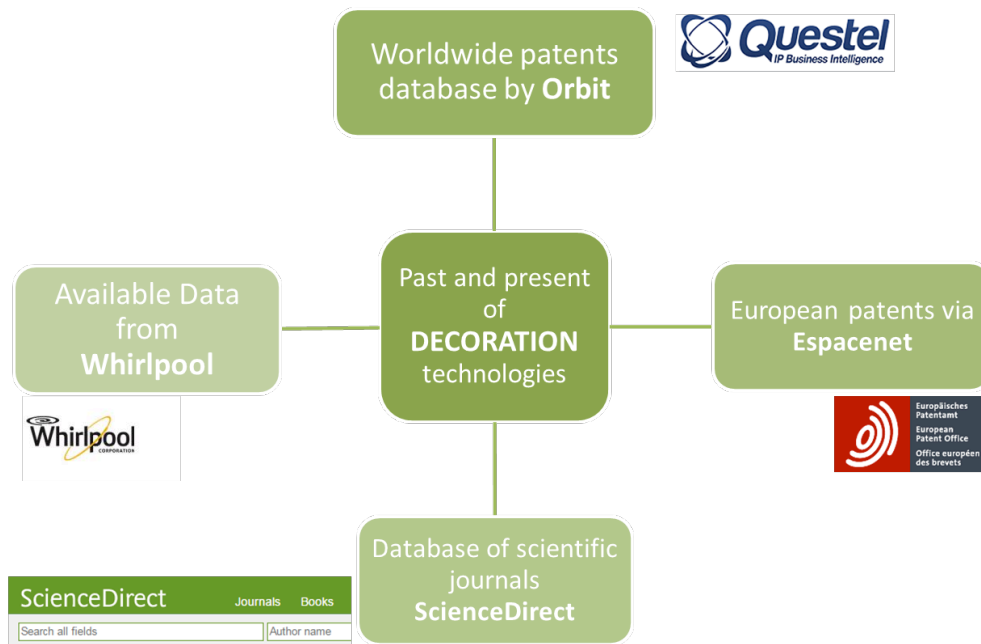
1. The Results of the previous Case Study done from April to June 2014. [1]
2. The presentation submitted by Mr. Michael Z.Cukier [2]
3. The presentation from Mr. Marco Urbaz (Whirlpool, Cassinetta) “Inkjet technology study”, 2013. [3]
4. 12 additional documents and reports about Laser marking and ink jet printing.
5. The presentation submitted by Pierluigi Petrali (Whirlpool, Cassinetta) “GCD CFM EMEA Roadmap / CFM EMEA Technical Solutions”, Mark Swanson, Oct. 2013. This presentation has been taken into analyses in order to see the trends about decoration. [4]
6. Whirlpool catalogues 2000 and 2014 in order to analyze how a decoration has been changed in order to catch the trends of decoration by itself, not by technologies. [5,6]



5.A. Documents used during study.

### 5.2. THE FOLLOWING DATA SOURCES AND DATA SERIES WERE USED

1. Worldwide patents database throw the Orbit search engine [16]
2. European patents via Espacenet
3. A database of scientific journals ScienceDirect in order to see the trends.
4. An available data from Whirlpool including the data as a result of factory visit 21-10-2014 at Wrocław.



5.B. Data sources and data series used during study

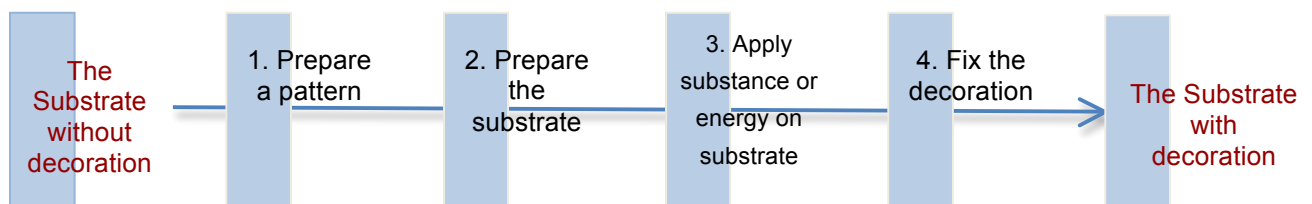
## 6. PROCESS DESCRIPTION

### 6.1. DECORATION PROCESS

6.1.1. In order to avoid professional biases and preconceived ideas about existing technologies for decoration [2], a generic functional description of process was elaborated. The function of decoration for home appliances was formulated as: <to produce> <colors and texture> <on the substrate> <permanently>. Thus, all kind of displays (e.g. monochrome and colorful LED display) and electronic means (e.g. electronic ink) to indicate information on the surface were excluded from scope of study.

6.1.2. Process is described using 6 stages in order to keep a model thinkable, since operational memory of human mind is limited by its capacity<sup>2</sup>.

6.1.3. Description, suggested on figure 6.A. is relevant for separate processes: screen printing, pad printing, laser marking, ink-jet printing, hot-stamping, chemical etching, embossing, liquid coating techniques, electroplating, vacuum deposition, plasma deposition etc. Presented flowchart is not appropriate when decoration is made in combination with other process – for instance, in-mold decoration.



6.A. Main stages of a generic decoration processes.

6.1.4. The substrate without decoration is an area of the surface on which an image (decoration) has to be placed. In context of reported study it can be a plastic or a metallic surface (metallic including: enameled, painted or inox).

6.1.5. For screen printing and pad printing, to (1) prepare a pattern is a time consuming part of process. There is a trend, that in coming future this operation will be done via digital printing concept.

6.1.6. The operation to (2) prepare the substrate is specific for different decoration technologies. The generic tendency is to reduce time for this operation and combination of (2) with other operations.

6.1.7. The function to (3) apply substance or energy on substrate is the main one. This is when <to produce> <colors and texture> <on the substrate> is performed directly. Various decoration techniques perform the function in a different way. For instance, for laser marking we do not apply any substances, but energy.

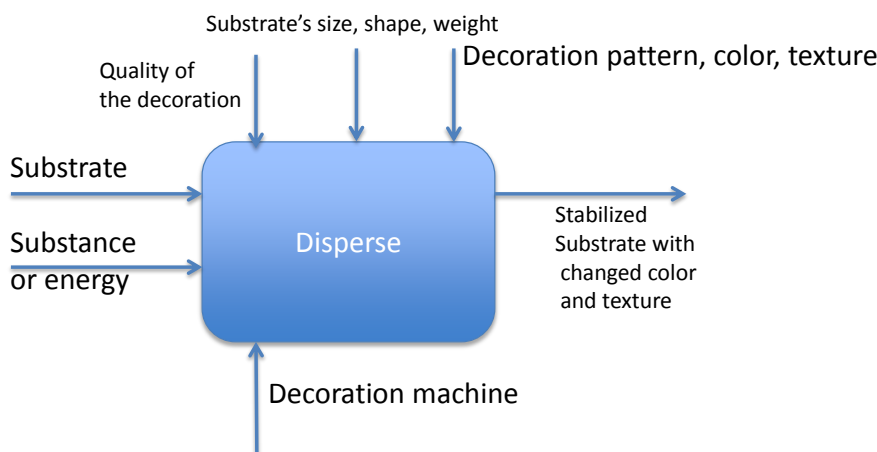
6.1.8. The operation to (4) fix the decoration takes different time for each technology. It can take from a second to minutes for curing formed image. For instance, a laser marking on steel substrate needs just a few seconds for fixing decoration. When, a laser marking on plastic surface needs more time.

<sup>2</sup> G. A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," Psychol. Rev., vol. 63, pp. 81–97, 1956.

6.1.9. Finally the substrate has chemically and mechanically resistant colorant (or metallic appearance) on top and its textures. Those recognizable colors and texture form what is called decoration.

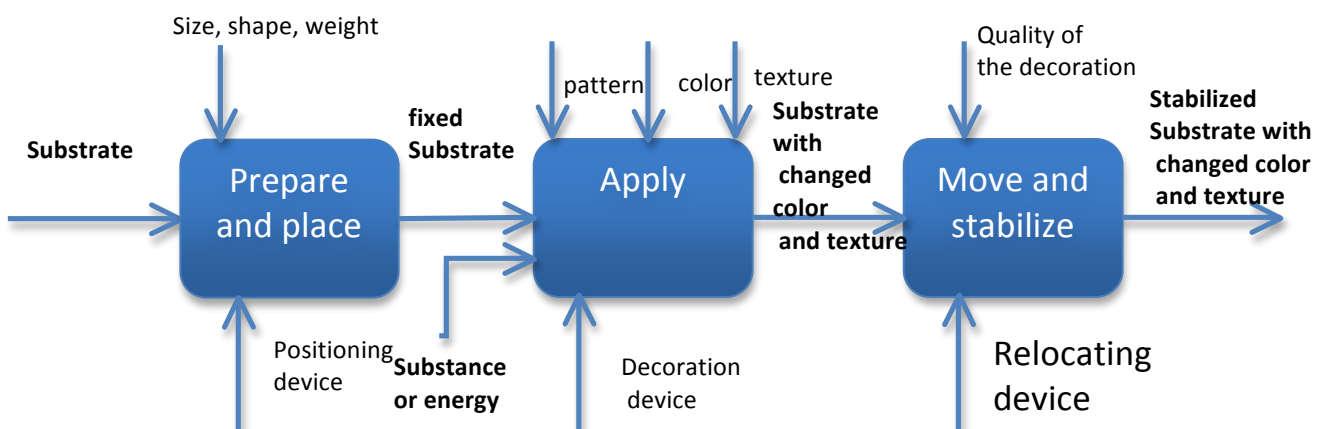
## 6.2. FUNCTIONAL MODEL

6.2.1. In order to specify flow of materials, available resources, and major constrains, the functional model of a generic decoration process was elaborated using IDEF0 notation: arrows connected to the bottom of boxes represent needed equipment; arrows connected to left side of the boxes signify necessary inputs; arrows connected to tops of boxes describe major constrains and control; arrows connected to the right side of boxes name outputs of function which written inside boxes.



### 6.B. Upper level of functional model for System to Forecast (STF)

6.2.2. The interpretation of figure 6.B. can be done the following way: <Decoration machine> <Disperses> <Substrate> and <Substance or energy> to produce <Stabilized Substrate with changed color and texture> controlled by <quality of the decoration>, <substrate's size, shape, weight>, <pattern, color, texture>



### 6.C. Second level of functional model for STF

6.2.3. These models were applied during study as a common language for learning about different decoration techniques.

### 6.3. MEASUREMENT THE PERFORMANCES AND THE EXPENSES

6.3.1. The presented criteria for measuring performance of future decoration processes were defined as result of study for applied technologies [1, 19] and alternative technologies [2, 3, 7-15, 18] in border of stage M. In order to define the criteria, following questions were stated:

“How would we estimate that the technology A is better (or worse) than technology B?”

6.3.2. The main evaluation parameters applied for decision making about next decoration technology are the following [1]:

- Geometry of the work pieces [substrate – How it will change in future?]
- Number of colors & Color gradient [aesthetic appearance – graphics]
- Thickness of graphics (numbers/letters/symbols) [aesthetic + resistance]
- Total cycle time

6.3.3. Meanwhile, the technical FEASIBILITY is defined by:

- Work pieces geometry
- Material of substrate
- Coat of substrate
- Graphics (number of colors, color gradient, thickness, metallic effect, resolution)
- Resistance

6.3.4. When the process COST depends on:

- Total cycle time ( throughput speed)
- Number of colors
- Size of graphics
- Equipment cost (initial investments, maintenance)
- Human resources

6.3.5. These factors were applied to study about applied, existing, alternative and potentially possible decoration technologies.

### 6.4. DECORATION PROCESS DESCRIPTION WITH SYSTEM OPERATOR

6.4.1. In order to organize collected information, to structure the process of information acquisition, and to guide the study, the System Operator technique<sup>3</sup> was applied. This technique had been suggested for supporting System Thinking within inventive problems solving process<sup>4</sup> (Fig. 6.C.).

6.4.2. There is a necessary minimum of definitions for understanding the System Operator (SO):

- *System* – is a group of interacting, interrelated, and interdependent components performing a certain function (system cannot operate without sub-system).
- *Super-system* – is the system where the selected System is the component (super-system cannot operate without System; in most cases a super-system is a process that needs the System).
- *Sub-system* – Sub-system – is a component of the selected System (necessary and sufficient components to perform the function of a System).

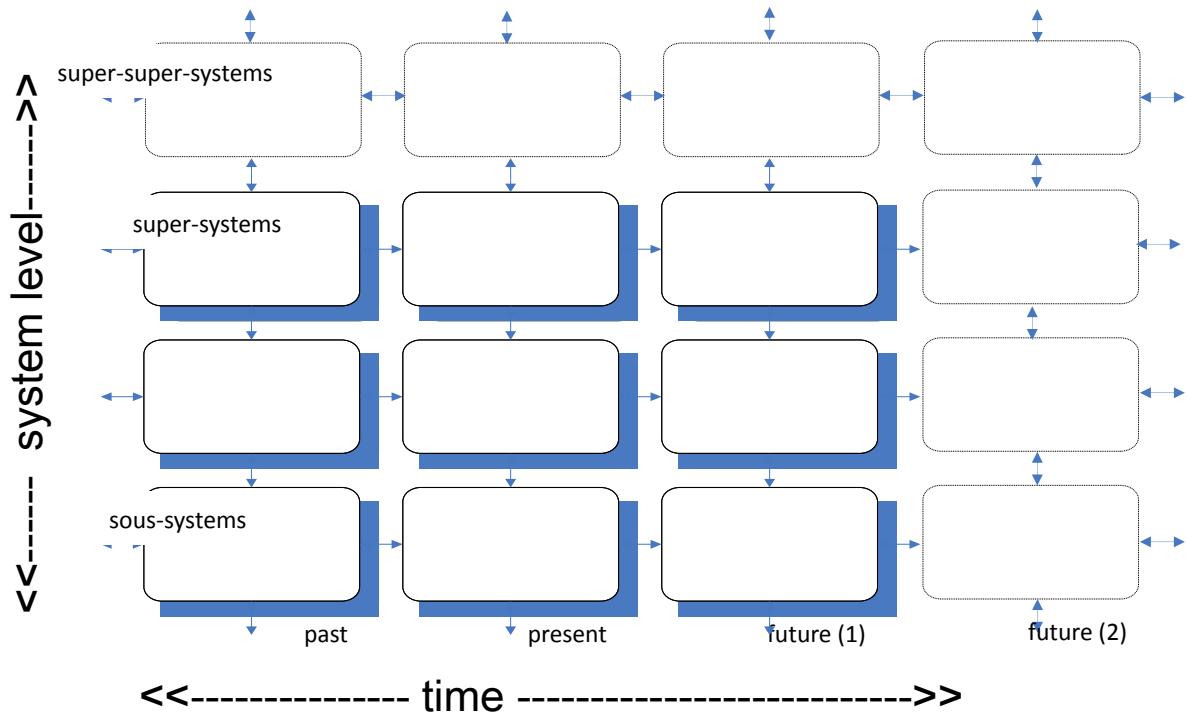
<sup>3</sup> also called Multi-Screen scheme of Talented Thinking

<sup>4</sup> G. S. Altshuller, Creativity as an Exact Science: The Theory of the Solution of Inventive Problems. Gordon and Breach Science Publishers, 1984, p. 320. (in Russian - 1979)

- *Neighbor-system* – is a component of a Super-system, relating to selected System.
- *Anti-system* – a system with an opposite function.

Each "screen" is applied for description in time at the particular level of system hierarchy. Linking arrows represent transitions and interconnections among screens.

6.4.3. System Operator description of present decoration technologies was elaborated for the purpose of *learning about the next technologies* with viewpoint of *working team, and specialists of WOCE group*.



6.D. System Operator and its screens

6.4.4. For the purpose of readability the levels of System, Sub-Systems, and Super-system are split into three figures.

The description of decoration process on the level of system can be found on figure 6.E. Definition of anti-system was developed for improving the formulation of the main function of decoration process. Comparison of feature for decoration processes in past (2004) and in present allows depicting some trends on the level of system and disclose some problems for future changes.

6.4.5. The description of decoration process on the level of Sub-Systems is presented on figure 6.F. Question marks on the screen about past indicate some lack of competence we faced during the study. Careful extrapolation of trends from past to present into future provides some hints about possible evolution of sub-systems of decoration process. Question marks on the screen about future signify uncertainties about recognized trends.

6.4.6. The decoration process from the level of Super-Systems is depicted on figure 6.G. This section of System Operator was used to study changes on the level of Super-Systems from past through present towards future. This part of study allows disclosing the reasons, driving forces and existing barriers on the way to the next decoration technologies. A structured description of the Super-Systems was developed by taking into account the four complementary contexts: Technological, Environmental, Economics and Social (TEES).

<p><b>Function: &lt;to produces&gt; &lt;colors and texture&gt; &lt;on the substrate&gt; &lt;permanently&gt;</b>                  Features* of decoration:</p> <ol style="list-style-type: none"> <li>1. One color (black); Two colors (less); Thick print (less); Texture (?) Metallic appearance (less)</li> <li>2. Cycle time to perform function</li> <li>3. Cost of function (lower)</li> <li>4. Resistance to damages during life-time of home appliance (less critical)</li> <li>5. less demand on customizable decoration</li> </ol>	<p><b>Function: &lt;to produces&gt; &lt;colors and texture&gt; &lt;on the substrate&gt; &lt;permanently&gt;</b>                  Features* of decoration:</p> <ol style="list-style-type: none"> <li>1. One color (diversity); - Two colors; - Thick print; Texture - Metallic appearance,</li> <li>2. Cycle time to perform function</li> <li>3. Cost of function</li> <li>4. Resistance to damage during life-time of home appliance</li> <li>5. customizable decoration</li> </ol>	<p><b>Function: &lt;to produces&gt; &lt;colors and texture&gt; &lt;on the substrate&gt; &lt;permanently&gt;</b>                  Features* of decoration:</p> <ol style="list-style-type: none"> <li>1. One color or No-color; - Two colors and more (??) - Shaped print (??); Texture diversity - Metallic appearance (more)</li> <li>2. Cycle time to perform function coordinated with production process</li> <li>3. Cost of function without major changes</li> <li>4. Improved resistance to damage during life-time of home appliance</li> <li>5. customizable decoration (!)</li> </ol>
<p><b>2004</b></p>	<p><b>2014</b></p>	<p><b>2024</b></p>

**Anti-system: <to remove> <colors and texture> <on the substrate> <permanently>**

6.E. Description on the level of System.

<ol style="list-style-type: none"> <li>1. Text, Graphics (lower resolution, smaller size, less languages)</li> <li>2. Technologies: silk screening, pad printing, laser marking, ink-jet printing less flexible (??)</li> <li>3. More options of Substrate: plastic, stainless steel                         <ul style="list-style-type: none"> <li>• geometry (flat, 2D, less curvatures)</li> </ul> </li> <li>4. Colorant:                         <ul style="list-style-type: none"> <li>• solvent ink; UV-curable (??)</li> <li>• processed substrate(?),</li> <li>• film(?)</li> </ul> </li> <li>5. Equipment (cost(?), simpler, less automatic)</li> <li>6. Human resources less educated (blue-collar), but more skillful</li> <li>7. Work pieces (less diversity) (less noble materials)</li> </ol>	<ol style="list-style-type: none"> <li>1. Text, Graphics (resolution, size, language)</li> <li>2. Technologies: silk screening, pad printing, laser marking, ink-jet printing</li> <li>3. Substrate: plastic, stainless steel, geometry (flat, 2D, 3D)</li> <li>4. Colorant:                         <ul style="list-style-type: none"> <li>• ink (solvent, UV curable),</li> <li>• processed substrate,</li> <li>• films</li> </ul> </li> <li>5. Equipment (overall cost)</li> <li>6. Human resources</li> <li>7. Work pieces</li> </ol>	<ol style="list-style-type: none"> <li>1. Less Text, More Graphics (higher resolution, size?, language?)</li> <li>2. Technologies: silk screening, pad printing, laser marking, ink-jet printing more flexible with more available options(TBC)</li> <li>3. Less options of Substrate: plastic, stainless steel,                         <ul style="list-style-type: none"> <li>• geometry more complex</li> </ul> </li> <li>4. Colorant:                         <ul style="list-style-type: none"> <li>• more ink (diversity of options and colors),</li> <li>• less options processed substrate (??)</li> <li>• Film(for laser marking?)</li> </ul> </li> <li>5. Equipment more automatic</li> <li>6. Human resources more educated (white-collar) but less skillful</li> <li>7. Work pieces (more diversity) (noble materials)</li> </ol>
<p><b>2004</b></p>	<p><b>2014</b></p>	<p><b>2024</b></p>

6.F. Description on the level of Sub-System.

<ol style="list-style-type: none"> <li>1. S: Process of aesthetic &amp; haptic perception of decoration (including distinction of a brand) - less demanding</li> <li>2. S: Home appliances (HA) products (e.g. refrigerator) - less decorated             <ul style="list-style-type: none"> <li>• Less complexity of HA</li> </ul> </li> <li>3. T, Ec: Production process for HA - less cost-effective, simpler             <ul style="list-style-type: none"> <li>• Greater size of a batch</li> <li>• Spare parts for 10 years</li> </ul> </li> <li>4. T, S, E: Life Cycle of HA (less requirements for recyclability &amp; reusability; longer; less manageable)</li> <li>5. S, E, T: Process to use HA (e.g. switch on, change mode) - less options</li> </ol>	<ol style="list-style-type: none"> <li>1. S: Process of aesthetic &amp; haptic perception of decoration (including distinction of a brand)</li> <li>2. S: Home appliances (HA) products (e.g. refrigerator)             <ul style="list-style-type: none"> <li>• Complexity of HA</li> </ul> </li> <li>3. T, Ec: Production process for HA             <ul style="list-style-type: none"> <li>• Size of a batch</li> <li>• Spare parts for 10 years</li> </ul> </li> <li>4. T, S, E: Life Cycle of HA (including recyclability &amp; reusability of materials)</li> <li>5. S, E, T: Process to use HA (e.g. switch on, change mode)</li> </ol>	<ol style="list-style-type: none"> <li>1. S: Process of aesthetic &amp; haptic perception of decoration (including distinction of a brand) is more demanding</li> <li>2. S: Home appliances (HA) products (e.g. refrigerator) - “minimalist” decoration             <ul style="list-style-type: none"> <li>• More complexity of HA (?)</li> </ul> </li> <li>3. T, Ec: Production process for HA - more cost-effective, sophisticated             <ul style="list-style-type: none"> <li>• Reduced (?) size of a batch</li> <li>• Spare parts for 10 years</li> </ul> </li> <li>4. T, S, E: Life Cycle of HA (more stress on recyclability &amp; reusability of materials and component)</li> <li>5. S, E, T: Process to use HA - is more oriented on elderly people; increased safety, and faultless work</li> </ol>
<b>2004</b>	<b>2014</b>	<b>2024</b>

6. G. Description on the level of a Super-System.  
 When, **T** – Technological, **E** – Environmental, **Ec** – Economics, and **S** – Social contexts accordingly

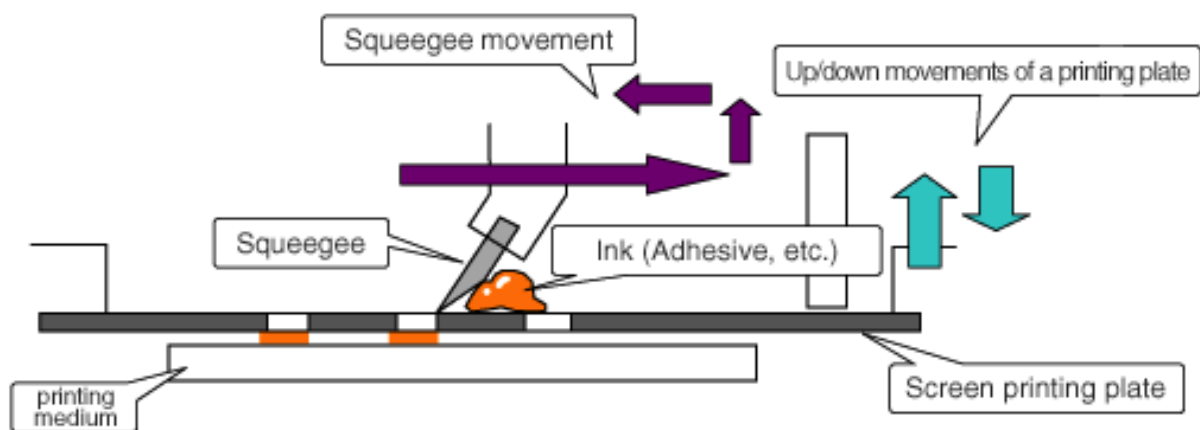
6.4.7. The results on screens of System Operator were regularly updated during the study. System Thinking approach and multi-screen description of decoration contributed essentially to assessment of alternative technologies (see section 7) and identification of major problems and drivers for technology changes (see section 8).

## 7. ALTERNATIVE TECHNOLOGIES

As it was presented in the section 6, the function of decoration process was defined as: *<to produce> <colors and texture> <on the substrate> <permanently>*. In accordance with the results of stage M (Model) and with forecasting questions, defined at stage FOR (FORMulate), the list of alternative technologies for further study was restricted to four main competitors: silk screening, pad printing, laser marking, and ink-jet printing. A brief description of alternative technologies is presented below.

### 7.1. SILK SCREENING

7.1.1. Silk screening<sup>5</sup> (also named as screen printing) is a printing technique that uses a woven mesh to support an ink-blocking stencil to receive a desired image (see also [19] for details).



7.A. Silk screening – squeegee movement<sup>6</sup>

7.1.2. A more detail description of silk screen technology was delivered within Decoration Round 1 study [1]. For the purpose of the second round of study we focused on short list of screen printing technologies: screen printing (static), screen printing (UV), and cylindrical screen printing<sup>7</sup>.

7.1.3. From the perspective of formulated forecasting questions (see section 3) the strong points of screen printing are: relatively short cycle time, printing in one pass, and large area printed in one pass. When the weak points are: difficulties when applying for curved surfaces, long time for pre-process (create design, silk screen, films, etc), only one color can be printed in one pass, and "one color more = one machine more".

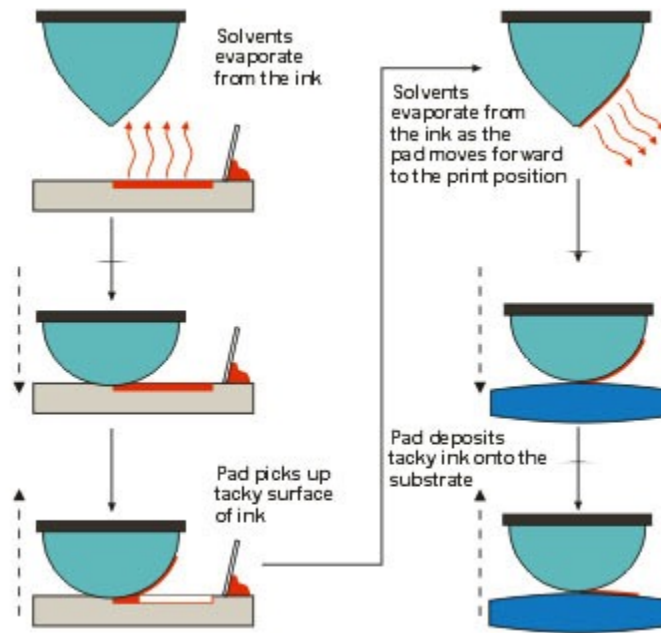
### 7.2. PAD PRINTING

7.2.1. Pad printing (also called tampo printing ) is a printing process that can transfer a 2-D image onto a 3-D object. This is accomplished using an indirect offset (gravure) printing process that involves an image being transferred from the cliché via a silicone pad onto a substrate<sup>8</sup>.

<sup>5</sup> Screen printing. (2014, December 7). In Wikipedia, The Free Encyclopedia. Retrieved from [http://en.wikipedia.org/w/index.php?title=Screen\\_printing&oldid=637071826](http://en.wikipedia.org/w/index.php?title=Screen_printing&oldid=637071826)

<sup>6</sup> <http://www.misumi-techcentral.com/tt/en/lca/2013/09/168-production-technology-level-up-course-for-machine-designers---30-screen-printing-technology.html>

<sup>7</sup> <http://www.printermaker.com/cylindrical-screen-printer-55-1.html>



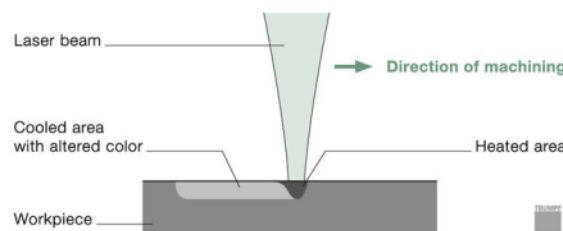
7.B. Pad printing cycle<sup>9</sup>

7.2.2. A detail description of pad printing can be found in report about Decoration Round 1 study [1]. For the purpose of this study we focused on truncated list of pad printing technologies: semi-automatic pad printing, automatic pad printing, and multi-axis pad printers<sup>10</sup>.

7.2.3. For the purpose of the formulated forecasting questions the strong points of pad printing were defined as: it can transfer image to a variety of surfaces: flat, cylindrical, spherical, compound angles, textures, concave, or convex; possibility to make several colors. The weak points we focused on are: a questionable resolution and esthetic for large surfaces (caused by pressure of the machine); no metallic decoration, limited flexibility to prepare colors, long time for pre-install films and clichés for new images, numerous films and clichés due to iterations for each new image (waste).

7.3. LASER MARKING ON PLASTIC SUBSTRATE

7.3.1. The principle of laser marking is that a laser beam somehow modifies the optical appearance of a surface that it hits.

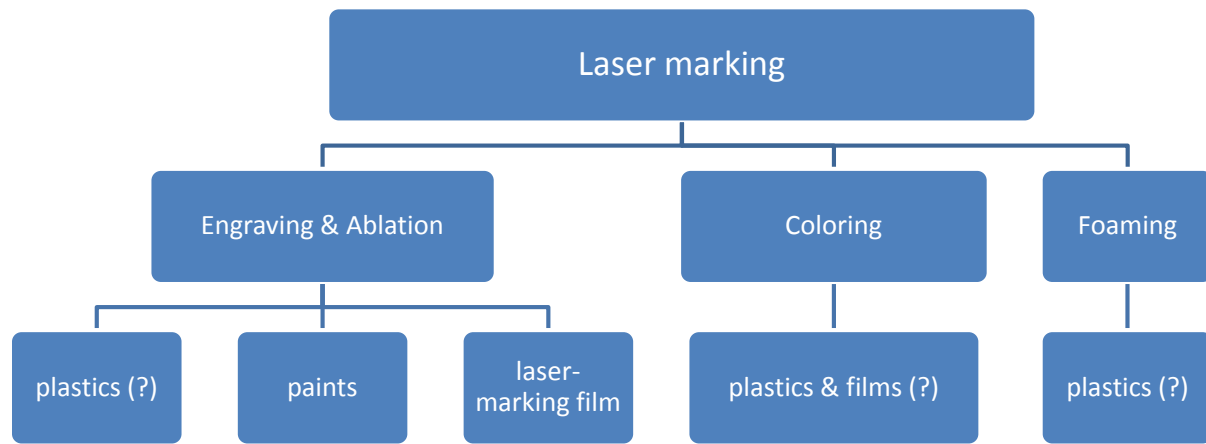


7.C. Generic principle of laser marking

<sup>8</sup> Pad printing. (2014, July 14). In Wikipedia, The Free Encyclopedia. Retrieved from [http://en.wikipedia.org/w/index.php?title=Pad\\_printing&oldid=616940729](http://en.wikipedia.org/w/index.php?title=Pad_printing&oldid=616940729)

<sup>9</sup> [http://www.pdsinternational.com/printing\\_information/processes/pad\\_printing.php](http://www.pdsinternational.com/printing_information/processes/pad_printing.php)

<sup>10</sup> <http://www.kentpp.com/pdf/KCNC.pdf>



7.D. Basic methods of laser marking on plastic substrates<sup>11</sup>

7.3.2. We focused our study of different laser marking technologies mostly on methods presented on figure 7.D. In accordance with objectives of study the strong and weak points of laser marking technologies were classified the following way:

STRONG POINTS	WEAK POINTS
high processing speeds thanks to digital printing	one color; limited color management; no known chrome or metallic appearance
low operation cost due to no use of consumables	costly maintenance; higher level of competence is required
constant high quality and durability of the decorations	costly utilities; spare parts are unique for particular application
avoiding contaminations	relatively high cycle time
the ability to form very small features	chemical resistance is questionable
flexibility in automation	relatively low operation cost effectiveness

7.3.3. The information about efficiency of laser marking for decoration on domestic appliances from different sources [8, 9, 10, 11, 12] sometimes is contradictory. It is suggested to check the questions of operation cost and chemical resistance through business case for particular application of laser marking technology.

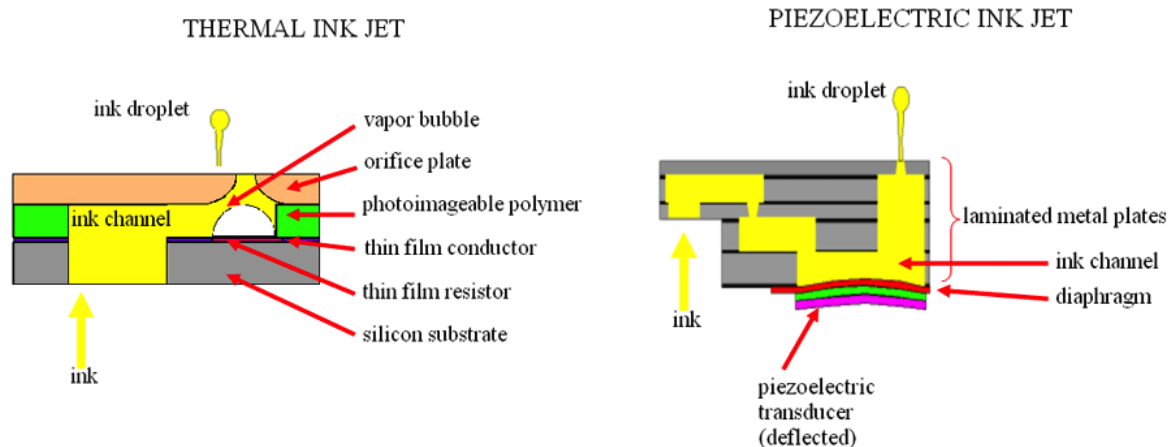
**7.4. INK-JET PRINTING**

7.4.1. The principle of inkjet printing is that droplets of ink are propelled onto the surface (in our particular case it is a plastic substrate) to modify the optical appearance of a surface.

7.4.2. Ink-jet printing technology was invented in 1951. Currently the family of ink-jet technologies is divided by method to generate droplets of ink to (1) thermal inkjet, and (2) piezoelectric inkjet. Ink-

<sup>11</sup> (1) RP Photonics Encyclopedia. RP Photonics Consulting GmbH. [http://www.rp-photonics.com/laser\\_marking.html](http://www.rp-photonics.com/laser_marking.html);  
 (2) TherMark technology: How it works: <http://www.thermark.com/content/view/16/86/>;  
 (3) Coloring and foaming <http://www.trumpf-laser.com/en/solutions/applications/laser-marking/coloring-and-foaming.html>

jet technologies also can be classified by types of applied ink: (a) solvent ink; (b) UV-curable ink; (c) dye sublimation ink<sup>12</sup>.



7.E. Two methods for generating droplets of ink<sup>13</sup>

7.4.3. In accordance with objectives of reported study the pro and con of ink-jet technologies on plastic substrates were grouped the following way [1, 3]:

STRONG POINTS	WEAK POINTS
digital image processing	increased process time for large surface
promised opportunities for future decoration: multi-color printing with high resolution (up to 720x1200dpi)	color management can be constrained by cartridge from suppliers; limited flexibility for creating new colors;
thin and long lines are possible to make; area graphics (photorealistic)	how to make the decoration with metallic appearance?
fast curing (depends on substrate and curing mechanisms)	tested ink performance is not adequate for corrosion and chemical resistance
short change over time between variants	
flexibility of decoration process (cycle time [s/pcs])	

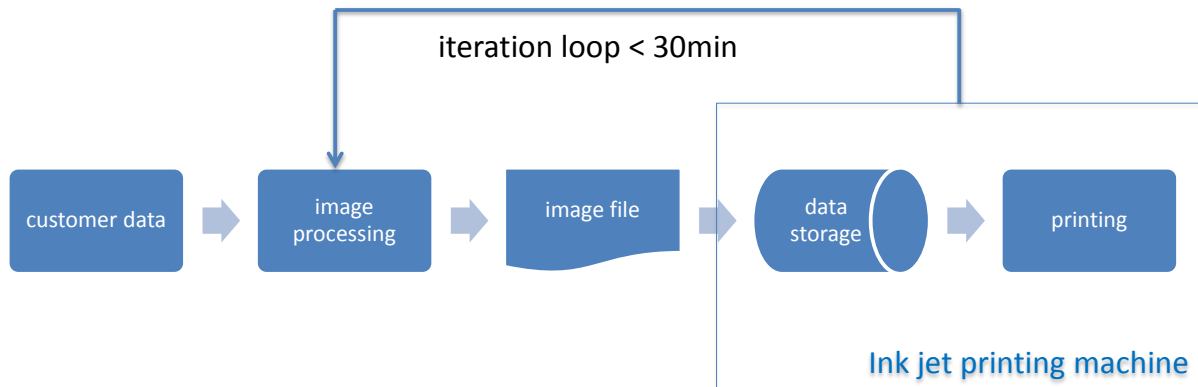
7.5. DIGITAL PRINTING

7.5.1. Ink-jet printing and laser marking are technologies that allow fast and efficient image pre-processing using digital methods. Both technologies belong to digital printing.

*Digital printing* refers to methods of direct printing from a digital-based (computer) image. These methods allow decreasing the iteration loop time manyfold.

<sup>12</sup> Inkjet printing. (2015). In Wikipedia, The Free Encyclopedia. Retrieved from [http://en.wikipedia.org/w/index.php?title=Inkjet\\_printing&oldid=643098135](http://en.wikipedia.org/w/index.php?title=Inkjet_printing&oldid=643098135)

<sup>13</sup> [http://www.imaging.org/ist/resources/tutorials/inkjet\\_printer.cfm](http://www.imaging.org/ist/resources/tutorials/inkjet_printer.cfm)



7.F. Iteration loop time and decoration process [3]

7.5.2. The capability for substantial reduction of the pre-processing time becomes very relevant in context of growing variety of required decorations (e.g. multi-lingual) and tendency to large variety of batch size for home appliance components and products. Reduction of long pre-processing time is important also for integrating the decoration process into main production process and avoiding buffer stocks.

Decoration technology	Site	# of models,		batch size range [pc]	
		2012	2014	2012	2014
Laser marking	Cas				
Silk screening	Wr				
Tampoprint	Wr	Data removed for confidentiality			
Tampoprint cold matrix	Wr				
Tampoprint hot matrix	Cas				
Engrave	Wr				

7.G. Batch size: cooking hubs (Cas – Cassinetta, IT; Wr – Wroclaw, PL)

## 8. MAJOR PROBLEMS AND LIMITING RESOURCES

The main lessons from study presented in sections 6 and 7 can be summarized as a set of problems that decoration technologies for home appliances struggle with. The logic of predicting future technology through learning about problems is straightforward – the next technology will answer today's problems.

Meanwhile, any problem is a result of the combination of a necessity (demand) and limited resources to satisfy the necessity. Therefore, for learning about problems it is worthwhile to realize what are the limiting resource beyond identified problem. In order to measure evolutionary transformation of decoration technologies measurement of limiting resources can be applied after generalization (see [pp.61, 62 in 17])

Whole set of the sixteen perceived problems was classified in accordance with system operator (see section 6.4) by three groups: problems on the level of system, problems on the level of super-systems, and problems from sub-systems.

### 8.1. PROBLEMS AND LIMITING RESOURCES ON SYSTEM LEVEL

#	PROBLEM	LIMITING RESOURCES
1.	a) How to print different colors (including metallic) with one technology? b) How to deliver haptic resolution with one technology (with the same expenses)?	available equipment, available colorants; printable substrates; minimum thickness of decoration's elements, tactile resolution of a person
2.	How to make decoration process in-line?	process time to perform the function [s]; flow of materials [kg]
3.	How to align cost of decoration process in connection with batch and aesthetic (and haptic) requirements?	Cost of a function; materials of surfaces for decoration and for substrate
4.	How to make decoration more resistant with different colorants and substrates (i.e. water resistance, chemical, abrasion)?	Adhesion forces, chemical and mechanical resistance of available colorants
5.	How to make digital printing applicable for different colors (including metallic) and different geometry on different substrates?	available equipment, available colorants; printable substrates, time of process

## 8.2. PROBLEMS AND LIMITING RESOURCES ON THE LEVEL OF SUB-SYSTEMS

#	PROBLEM	LIMITING RESOURCES
1.	How to make decoration digitally with higher resolution for larger size for the adequate cost and process time?	process time, attachment forces of a high resolution dot, size of a dot (valid for one color decoration)
2.	How to satisfy aesthetic requirements with 2-3 technologies and improve controllability of decoration process?	degree of freedom <sup>14</sup> of decorating head, pre-process time (iteration loop time printing-image processing)
3.	How to reduce number of technologies (hardware+software+orgware) (2-3 hardware=machines) when variety of substrates (and geometries) increases?	degree of freedom of decorating head, number of machine, knowledge= software, requirements=orgware
4.	How to use a lesser amount of colorants with more aesthetic options on the output?	resolution, results of combination of available colorants
5.	How to manage complexity of more automatic equipment when limited high-skill workforce?	number of elements, number of instructions, high-skilled workers
6.	How to have a human resource capable to switch from one technology to another with no reeducation?	time and cost of education, level of complexity of new technology

## 8.3. PROBLEMS AND LIMITING RESOURCES ON THE LEVEL OF SUPER-SYSTEMS

#	PROBLEM	LIMITING RESOURCES
1.	a) How to make decoration attractively distinguishable at glance? b) How to make decoration attractive and distinct by touch?	visibility of decoration, human preferences; materials of surfaces for decoration and for substrate;
2.	a) How to decrease amount of decoration (to be “minimalist”) when increasing complexity of home appliances (HA)? b) How to manage decoration process in context of complex production process?	space for decoration; many required elements for permanent decoration; number of operation for manufacturing process
3.	a) How to decrease change over time and manage equipment (materials) for reduced size of batch? b) How to produce spare parts during 10 years without stock when new decoration in production?	production time, available equipment, available colorants; available equipment, available materials;
4.	How to recycle components of HA with decoration without disassembling or special treatments?	time for recycling, energy for recycling, recycling cost
5.	a) How to inform users of HA with less decoration about more available options? b) How to make decoration explicitly understandable for elderly people?	time to learn, amount of information, decorated space; learning capacity, space for decoration, previous knowledge

<sup>14</sup> Degree of freedom. [http://en.wikipedia.org/wiki/Six\\_degrees\\_of\\_freedom](http://en.wikipedia.org/wiki/Six_degrees_of_freedom)

### 8.4. LIST OF MAJOR PROBLEMS AND LIMITING RESOURCES

This set of problems was created by screening and scoring the sets of problems presented above when using viewpoint of Whirlpool WOCE professional.

#	PROBLEM	LIMITING RESOURCES
1.	How to make decoration process in-line <sup>15</sup> ?	process time to perform the function [s]; flow of materials [kg];
2.	How to make digital printing applicable for different colors (including metallic) and different geometry on different substrates?	available equipment, available colorants; printable substrates, time of process
3.	How to make decoration digitally with higher resolution for larger size for the adequate cost and process time?	Process time, attachment forces of a high resolution dot, size of a dot (valid for one color decoration)

In order to be implemented at Whirlpool Europe factories in coming 5-10 years, future decoration technologies for home appliances have to provide explicit answers for major problems and to satisfy limiting resources.

<sup>15</sup> in-line decoration process – means making decoration when producing product (e.g. washing machine), but not in advance or apart of main production process.

## 9. PATTERNS OF EVOLUTION

9.1. TRIZ body of knowledge was used to understand the patterns of evolution of the alternative technologies.

9.2. Each alternative technology was represented by using Network of Evolutionary Trends logic, which allows understanding from engineering perspective which are the current inventions related to the System to Forecast (STF).

9.3. Different patterns are represented by branches and boxes. The three-boxes were filled according to several patent search developed by FORMAT-workteam. The different patterns search are included in an excel-file allowing to the beneficiary obtain more detailed information if required.

9.4. The color boxes represent, if an evidence exists, inventions trying to address that particular pattern. Grey boxes are those patterns that have been addressed by at least one patent or invention. Green boxes are potential branches that seem to be not currently addressed by patents or inventions – according to patents and data search developed by FORMAT-workteam.

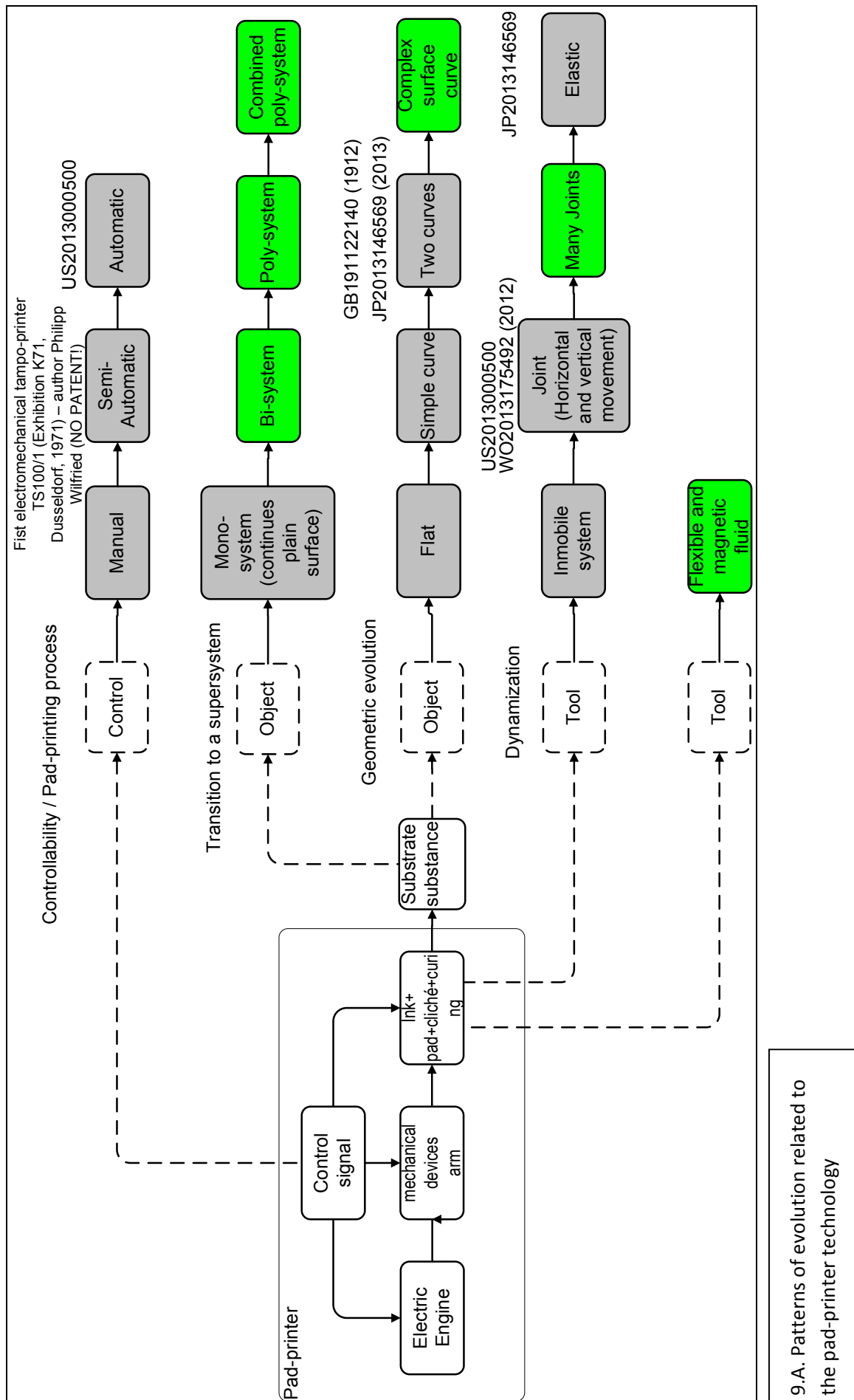
9.5. There are several common patterns among these four technologies, such as:

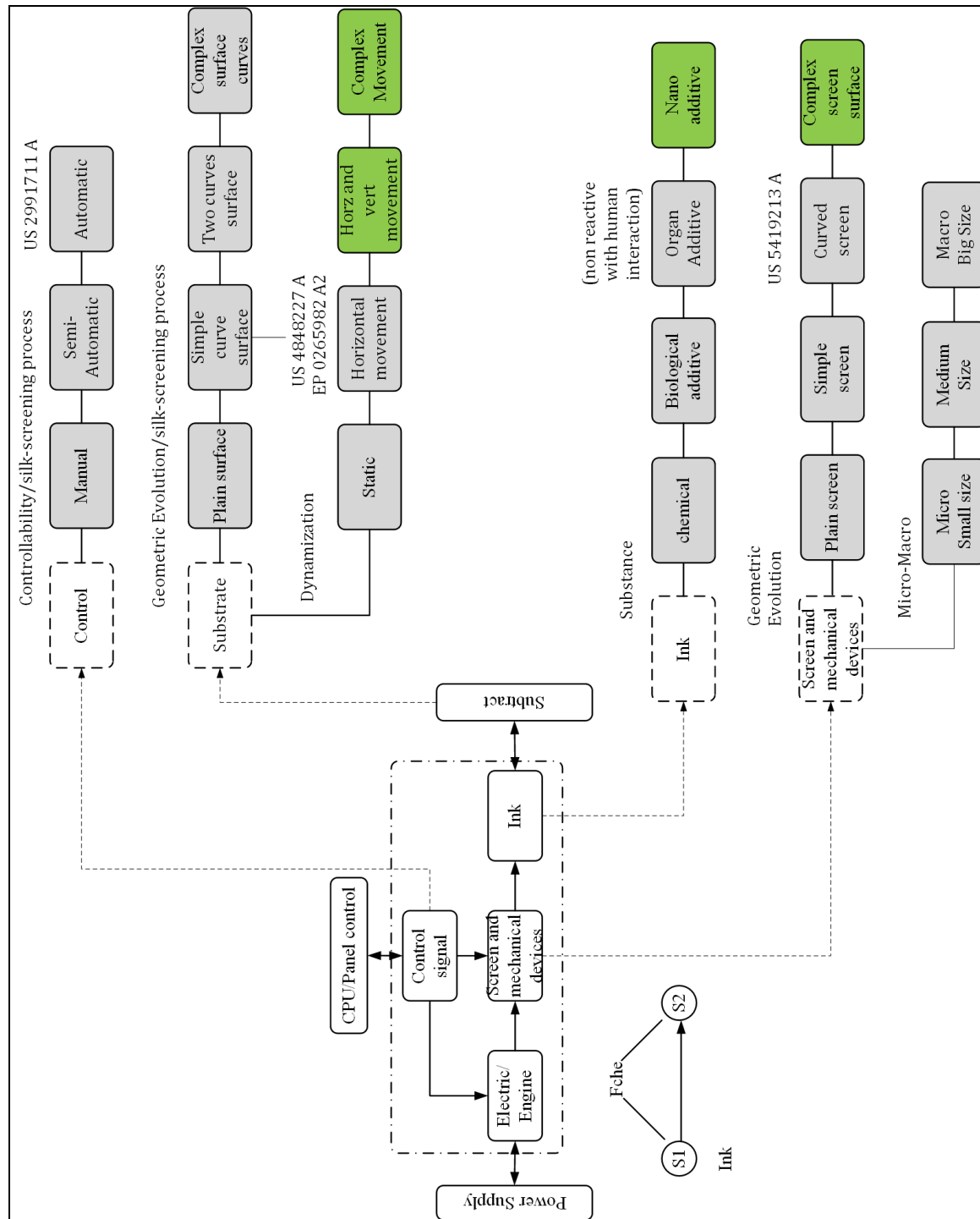
- i. Patterns related to the surface which technologies are capable to print/mark (geometry evolution);
- ii. Patterns related to the tool's flexibility to print (dynamization);
- iii. patterns related to the needed resources to print (ink or energy).
- iv. Patterns relate to the control of the system (controllability)

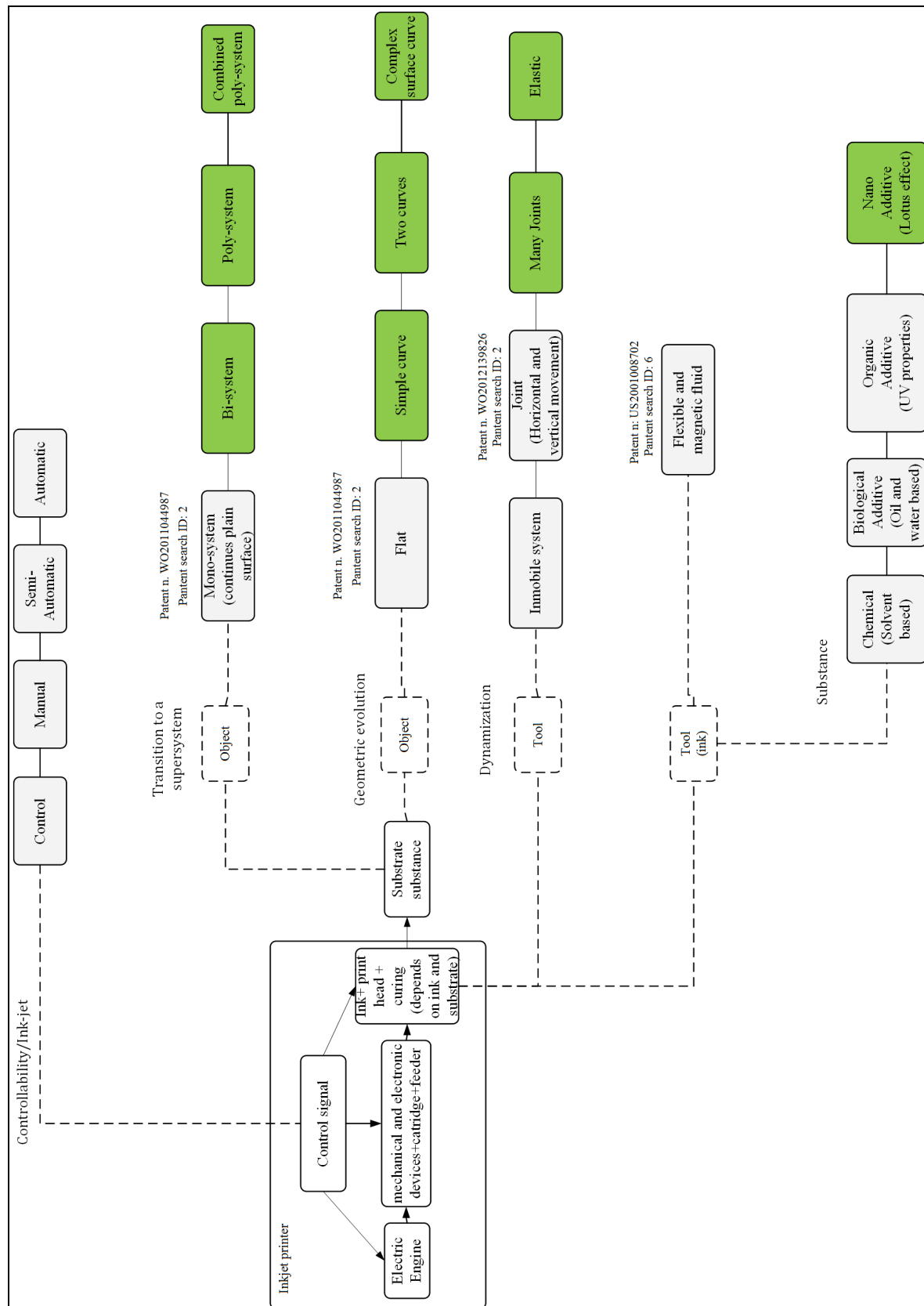
9.6. Patterns are more frequent in some technology than others. For example, pad-printing and laser-marking showed by patents that are more capable to print different surface than silk-screening and inkjet printing.

9.7. From pictures, it is possible to see that Inkjet technology seems to have more advanced research in terms of inks than pad-printing and silk-screening.

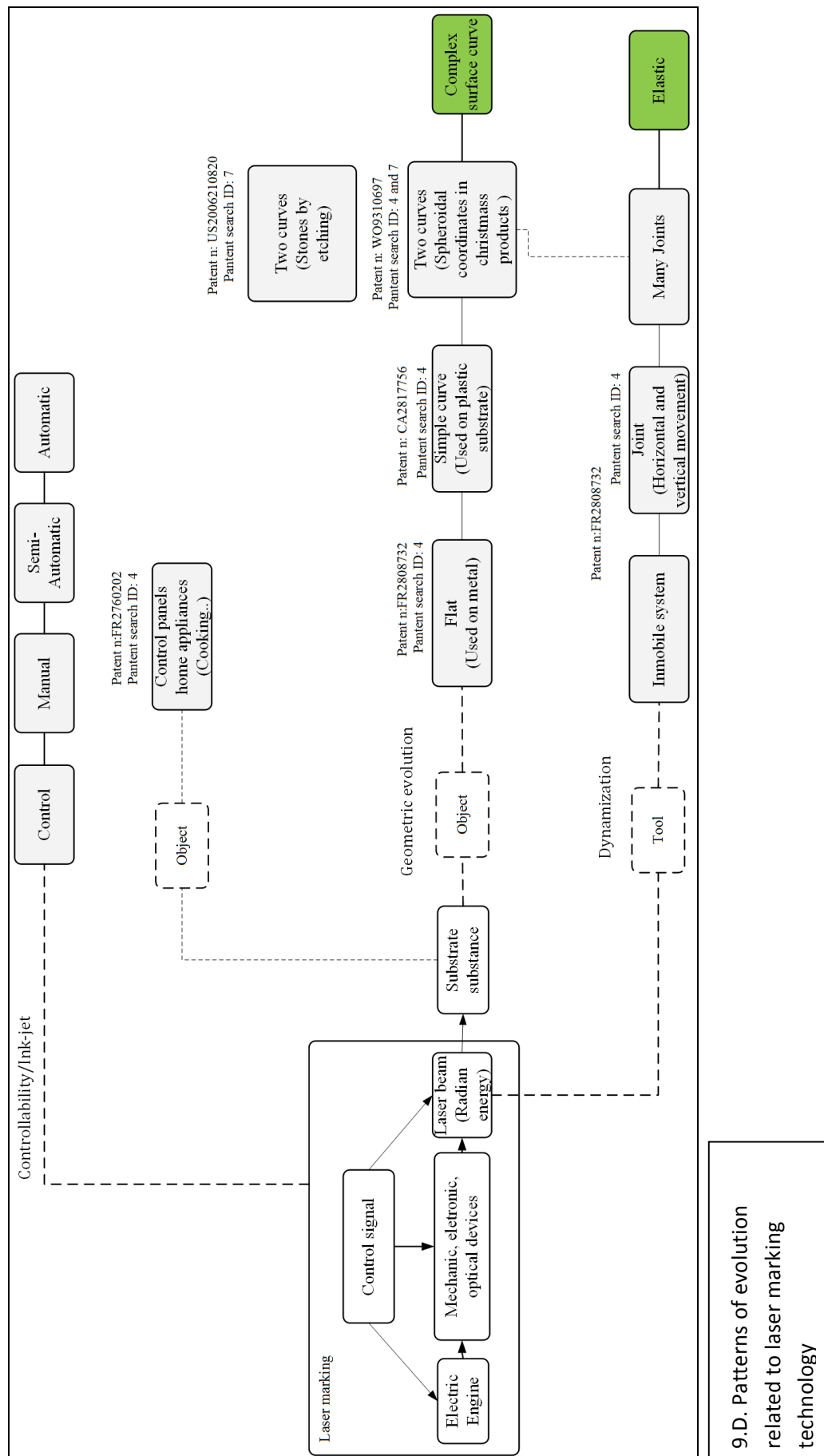
9.8. The identification of the best features of technologies related STF (<to modify><colors><surface>) largely depends from customer's needs.







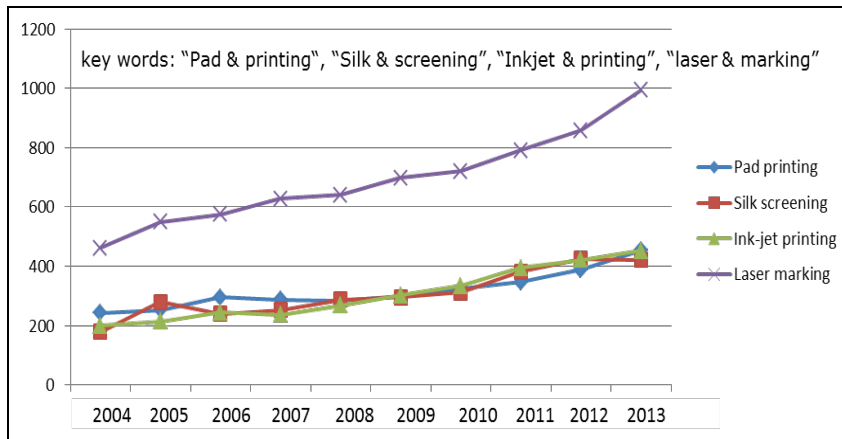
9.C. Patterns of evolution related to inkjet technology



## 10. RESULTS OF DATA ANALYSIS

10.1. The quantitative analysis allows to obtain a better understanding of the technology evolution. From collecting data process, the data was collected mainly on external data sources as patent and scientific databases as (European Patten Office and ScienceDirect)

10.2. First quantitative graph was developed by collecting the number of publications related to the alternative technologies. Keywords used for data collection have been defined during the activities of the FORMAT case-study.



10.A. Trend on publications related to STF (number of papers per year)

10.3. Second quantitative graph was developed by collecting the number of patents related to the alternative technologies. Data collection was based on keywords and Cooperative Patent Codes related to these technologies. The patent search was developed with Orbit-engine. Table presents the keywords used during the patent search.

STF	Keywords	CPC*
General(function)	(colour+ OR color+) AND plastic+ AND surface+	B41F AND B41M AND B41J
silk and screening	(colour+ OR color+) AND plastic+ AND surface+ AND (silk+ AND screening+)	B41F
pad printing	(colour+ OR color+) AND plastic+ AND surface+ AND (Pad AND Printing)	B41F
laser marking	(colour+ OR color+) AND plastic+ AND surface+ AND (laser+ AND marking+ )	B41M
Inkjet	(colour+ OR color+) AND plastic+ AND surface+ AND (inkjet 2D printing)	B41J

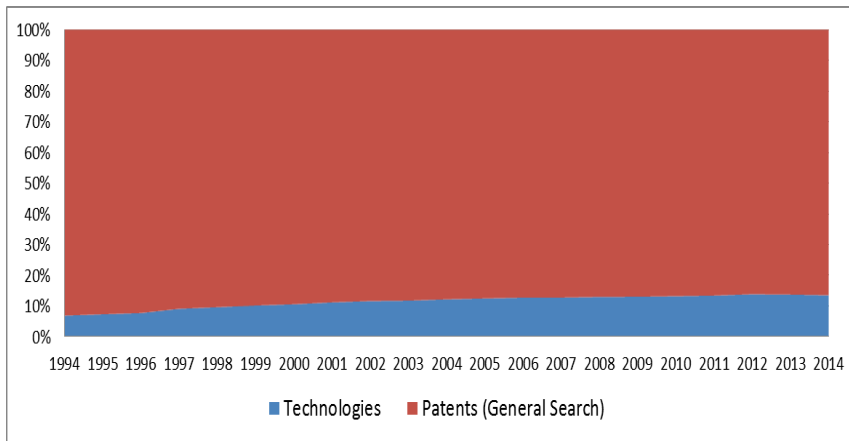
\*Cooperative Patent Classification (CPC):

**B41F** – PRINTING MACHINES OR PRESSES

**B41M** – PRINTING, DUPLICATING, MARKING, OR COPYING PROCESSES ; COLOUR PRINTING

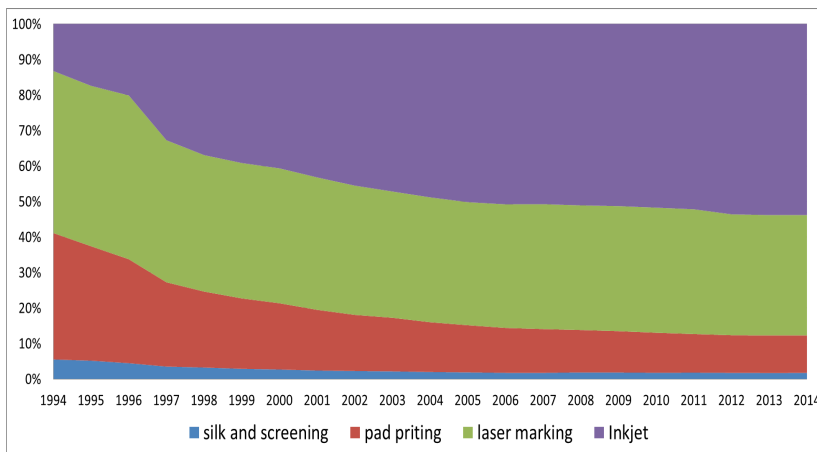
**B41J** – TYPEWRITERS; SELECTIVE PRINTING MECHANISMS, (e.g. INK-JET PRINTERS, THERMAL PRINTERS)

10.4. With the collected patents, a relative comparison was developed between the patents related to the "General Search" (General – as defined in table in point 10.3) and those patents specifically related to the alternative technologies. Results showed that only a small percentage of patents are related to the alternative technologies. The overall set of alternative technologies studied in this case study represents only the 10% in terms of number of patents. The red area – is a field of some unknown technologies related with printing.



10.B. Relative comparison among general patent search (function) and those related to the alternative technologies (cumulative patent number)

10.5. From what concerns to those patents related to the alternative technologies. A second relative comparison was developed in order to understand the distribution of the patents in the last 20 years. The relative percentage is considered by cumulative patents number per years.



10.C. Relative comparison among alternative technologies (cumulative patent number)

10.6. Results showed that inkjet technology has a higher percentage of patents than other alternative technologies. The silk-screening technology presents the lower relative percentage during the last 20 years. The relative percentage of patents of the pad-printing technology has been decreased during the last 20 years. The relative percentage of patents related to the laser marking technology seems to be quite stable during the last 20 years.

10.7. Limitation of data for the specific alternative technologies does not allow to bring more significant results in order to understand which one will be the used at WH facilities.

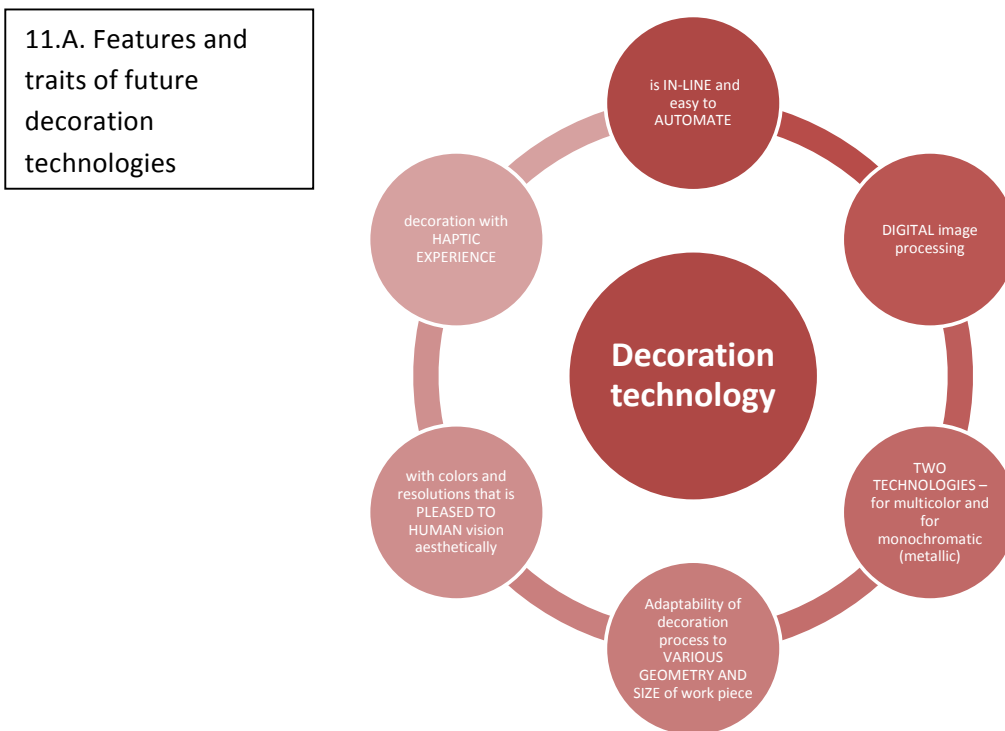
## 11. FUTURE OF DECORATION TECHNOLOGY

For answering the questions we do not name a specific technology but we describe the features and main traits of the next technology or family of technologies.

### 11.1. TRAITS OF FUTURE DECORATION TECHNOLOGY

**Which is the most promising decoration technology for achieving present and future product need in coming 5-10 years at Whirlpool European factories?**

1. The decoration technology in the future undoubtedly has to be in-line and easy to automate.
2. Digital image processing is inevitable for future decoration processes. It is not possible to evolve decoration technologies without digital image processing in these days.
3. In 5 to 10 years it will be not only one technology to satisfy demanding needs, but at least two technologies or a family of complementary technologies. It is difficult to believe that only one technology can answer demands from perspective of performance/cost ratio.



4. Adaptability of decoration process to different geometry and size of workpieces should increase without increasing complexity of equipment. For instance, printing on flat surface and on the cylinder shall be possible with quick adding a simple device to existing machine.
5. The number of colors and resolution of decoration will not grow endlessly. Number of colors and resolution will grow until they satisfy Human vision aesthetically. It means that if yesterday the resolution of decoration was 300 dpi, tomorrow it won't be 3000 dpi.
6. Future decoration will provide haptic experience to customers. Therefore, next technologies should support not only two-dimension (2D) decoration but also 3D decoration. The decoration applied for computers, smartphones and cars already provide both – visual and haptic experiences.

**First.** A decoration process, that is integrated into production process of home appliance and easy for automation can be achieved at least in three different ways:

- when cycle time of decoration process is in in flow with cycle time of whole production process; the decoration is created when a product (e.g. washing machine) is produced; (this is the target for future decoration for WOCE product group at Whirlpool EMEA)
- when decoration process is combined with other operations; for instance, in-mold decoration – when decoration is made within forming a plastic part; decoration can be combined also with assembly, transportation or other in-line operations;
- when the decorated components are received in advance from suppliers – it is not integration in real sense, but a solution (sometimes applied today) that causes a stock of components (buffer).

**Second.** Whatever technology will be applied for decoration in future (next 5-10 years) the time for iteration loop<sup>16</sup> has to be less than 20 min. The shorter time is preferable in situation when size of batch may vary from several to several hundred pieces.

**Third.** At least two technologies will be applied for optimizing the ratio "performance vs. cost-time" of decoration. One technology will provide an adequate ratio for multicolor (more than 3 colors) decoration for different substrates. Meanwhile, another technology will provide the best ratio for monochromatic (including the metallic appearance) decoration. There is strong evidence that in coming 5-10 years at European market most of components will use monochromatic decoration [4, 5, 6].

**Fourth.** Next decoration technology will perform satisfactorily without significant additional cost-time expenses and without growing complexity of applied equipment. The same machines with help of simple devices will be applied for flat surfaces or for curved substrates. Next decoration technologies will keep the same fraction of cost-time when compared with whole production process. Decoration cost will be about 1% and less of production cost of whole item (less than 1% in ovens, 0,14% in refrigeration, 0,3% in washing, 0,6% in dishwashers).

**Fifth.** Quality characteristics of decoration in future will not depend on technical capacities or on size of decoration image. Whatever size of decoration will be required on flat or curved surfaces the decoration features will be invariable. Meanwhile, the quality parameters of next decorations will be defined mostly by limits of human "sensors" – vision and tactile.

**Sixth.** Haptic component for interacting with technical systems has growing potential currently. Next decoration will provide not only pleasant and comfortable visual experience, but haptic one also. This trend about haptic experience is recognized today for decoration on smartphones, computer systems, and car interior. Another aspect about haptic part of decoration is linked with weak eyesight for aging population. For aged population in Europe, we expect to meet in coming 10-15 years, the haptic features of decoration will be more significant than today.

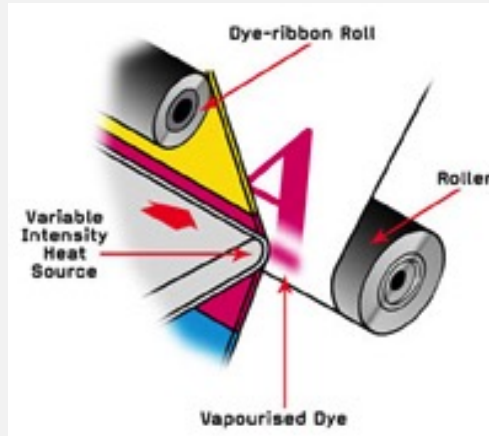
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<sup>16</sup> time to modify decoration pattern, size, or colors e.g. for pad printing a workflow: customer data – preprint – film production – cliché production – printing, takes  $\geq 2$  days [3];

### Thermal Ribbon Dye Diffusion Printers

This technology was recognized when the list of traits was developed. First time, the dye-sublimation was considered in 1957 in context of printing technologies.

Thermal Ribbon Dye Diffusion printers [13, 14] are thermal printers that utilize dyes, resins and metallic coated directly onto a ribbon.



source of figure: <http://www.abcoffice.com/office-equipment-news/2011/01/what-is-dye-sublimation-id-card-printing/>

"Each minute pixel in a thermal head transfers the dye or resin, either directly onto the substrate or through the use of a retransfer process directly onto the substrate" [13].

"Traditionally, the advantage of dye-sublimation printing has been the fact that it is a continuous-tone technology, where each dot can be any color. In contrast, inkjet printers can vary the location and size of ink droplets, a process called dithering, but each drop of ink is limited to the colors of the inks installed. Consequently, a dye-sublimation printer produces true continuous tones appearing much like a chemical photograph. An inkjet print is composed of droplets of ink layered and scattered to simulate continuous tones, but under magnification the individual droplets can be seen" [18].

It is not clear until now will the Thermal Ribbon Dye Diffusion technology be the next step in decoration on plastic substrates for home appliance. However, it corresponds for many features of next decoration technology, recognized in border of reported study. It agrees also with trends of evolution for pad printing techniques (see section 9), confirmed by some patents.

The Thermal Ribbon Dye Diffusion looks like a hybrid: it presents features of pad printing and ink-jet printing in the same time. When considering the working principle there are some similarity with hot-stamping technology applied for metallic appearance decoration.

## 11.2. EVOLUTION OF INK-JET AND LASER MARKING TECHNOLOGIES

### Which will be the expected (estimated) evolution of Main Parameters of INK-JET and LASER MARKING in future 5-10 years for European home appliances?

MAIN PARAMETERS	Ink-Jet	Laser Marking
In-line and Automation	to be improved	possible with limitations
Digital image processing	adequate	adequate
Multi-color / Monochromatic	adequate / improvement for metallic appearance	required improvements for plastic substrate
Substrate geometry and size	major improvement	minor improvement
Aesthetic appearance	required improvement	minor improvement for inox
Haptic experience	how to make?	possible to make

## 11.3. TECHNOLOGY SUBSTITUTION

### 11.3.1. When will Ink-jet technology be ready to substitute silk screening and pad printing for domestic appliances?

Ink-jet technologies are ready to perform functionality for Decoration for domestic appliances. The business case study has to be developed to define cost efficiency for particular applications. Alkali resistance and solvent cleaning resistance issues, reported in 2013 [3] have to be checked again for solutions from leading innovators (e.g. BASF group) [p. 126 in 17] and not only for Mimaki Engineering, Japan.

For successful application of Ink-jet technologies, it is inevitable to grow competence about ink formulation. With adequate competence about ink preparation, it is potentially possible to make unlimited colors of decoration, including the metallic appearance. Some machines available on the market present adequate adaptability to curved and shaped substrates [7].

### 11.3.2. When will Laser Marking be completely able to produce colored marks in plastic?

Laser Marking technologies produce colored marks on metallic (stainless steel) substrate [12]. During reported project the machines and suppliers (capable to make multi-colored laser marking on plastic substrates with required quality of decoration) were **not identified**. Meanwhile, the technologies for monochromatic laser marking on plastic are quite known.

When applying laser beam on plastic substrate the changeable parameters are intensity of laser beam ( $W/cm^2$ ), frequency of pulsing laser beam, material of substrate, optical focusing and direction of treatment. Therefore, there is endogenous constrains for multi-color appearance without deposition of specific substances.

Color of laser marking decoration depends essentially on properties of substrate materials. In order to change a color of decoration, it is necessary to vary the material of component. Meanwhile, the material of component is defined by mechanical, esthetic and other requirements for entire product (e.g. refrigerator, hub, oven).

## 12. WORKING TEAM

Name - affiliation	Location
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## 13. APPENDIX

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### 13.2. RESULTS OF STAGES FOR, M, A, T

See the following document:

**Slides from working sessions. Case study: Decoration, Round 2.** October-December 2014, Milano-Cassinetta, Italy [Annex FORMAT Session slides.pdf]

<b>Revision History</b>			
<b>Revision</b>	<b>Changes</b>	<b>Date</b>	<b>Prepared By</b>
1	Comments by Katarzyna Różycka – discussed, reviewed, adapted by Mateusz Słupiński	22/01/2015	Mateusz Słupiński
2	Comments by Igor Kaikov – reviewed, adapted by Mateusz Słupiński	26/01/2015	Mateusz Słupiński
3	Internal English-language check	26/01/2015	Mateusz Słupiński