# Industrial Digital Color Printing Press for the Plastic Card Industry

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## Abstract

Today the plastic card and more precisely the smart card (chip card) market is growing very fast in all segment applications (mobile phone, bank, identity and loyalty,..). This growth comes also with the request from the customer and/or the application to have a customized product in a very large scale of production batches, from few cards to few million cards. We have to combine large volume production with individual personalization that makes the card unique. The analysis of the different card manufacturing processes shows a bottleneck at the printing and graphical personalization stage.

Traditional offset printing does not offer to card issuers the opportunity to print multiple card designs in a single run. Other printing technologies are not compatible with an industrial environment in terms of speed and cost. The target for final customers is to have a unique product at a very low cost.

This problem is today a difficult reality and the plastic card manufacturers and related suppliers are looking for solutions meeting positively this demand.

This document describes the development of an industrial inkjet color printing press for plastic card. The different development steps will be detailed including the customer need, the selected technology and partner, equipment, the print engine development, the technical and economical results in production.

## Introduction

The smart card is one of the latest additions to the world of information technology. Similar in size to today's plastic payment card, the smart card has a microprocessor or a memory chip embedded in it. The chip stores electronic data and programs that are protected by advanced security features. When coupled with a reader, the smart card has the processing power to serve many different applications.

As an access-control device, smart cards make personal and business data available only to the appropriate users. Another application provides users with the ability to make a purchase or exchange value.

Smart cards provide data portability, security and convenience.

## Applications

The list of potential applications for smart card technology would be too long for this document. Instead, you can find listed below some of the major applications seen around the world.

There are over 400,000,000 GSM mobile telephones with smart cards containing the mobile phone security and subscription information. The handset is personalized to the individual by inserting the card that contains his/her phone number on the network, billing information, and frequently call numbers.

Almost every small dish TV satellite receiver uses a smart card as removable security element and subscription information. There are over 4 millions of cards in the US alone between DirectTV, USSB and Echo Star. There are millions more in Europe and Asia.

The Financial industry has rapidly adopted smart card technology in various countries around the world. Every French Visa Debit card (over 25,000,000) has a chip in it. In Germany, about 40,000,000 banking cards have been issued. All EuroPay, MasterCard, and Visa have smart card programs for their bank members. In Portugal and Singapore, the national banking networks have launched electronic purse projects. Proton has worked with its banking partners to issue over 25,000,000 electronic purse cards in several countries.

Various countries with national health care programs deployed smart card systems. The largest one is the German solution that deployed over 80,000,000 cards to every person in Germany and Austria.

There are over 100 countries worldwide that reduced or suppressed coins from the pay phone system by issuing smart cards. Germany, France, UK, Brazil, Mexico, and China have major programs.

Other applications for smart cards include computer/internet user authentication and non-repudiation, retailer loyalty programs, physical access, resort cards, mass transit, electronic toll, product tracking, national ID, driver license, passports, and the list goes on.

All these different applications require to have each card different from the others, each card is unique and personalized with the data of its owner.

## Manufacturing Processes

The manufacturing of all different types of smart card involves various flows that can be summed up into two main processes:

- Injection molding
- Lamination

In fact, injection molding or lamination only describes the card body manufacturing. This card body receives along the manufacturing flow different processes that will generate the complete smart card product. On the following figure 4, you can see the description of different manufacturing flows (the chip or module manufacturing process is not described).

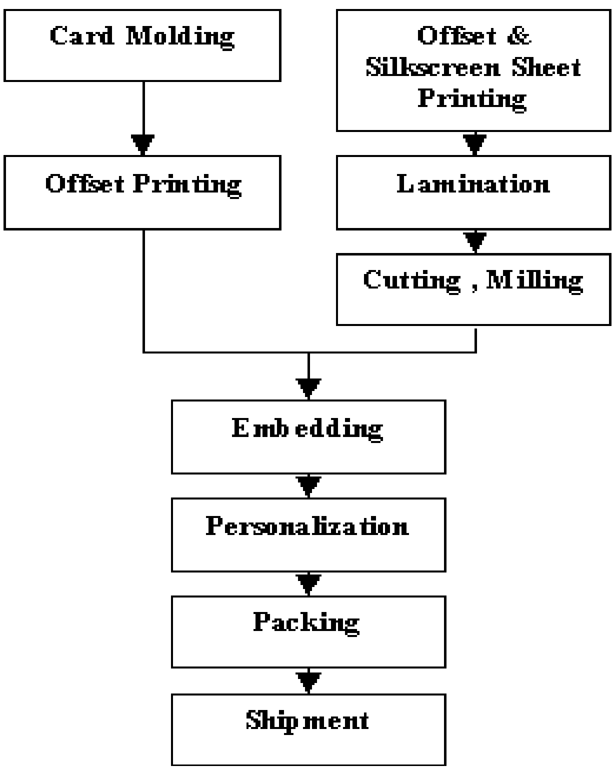


*Figure 1. Smart Card manufacturing flow*

The used printing processes are based, in both cases, on offset technology for printing the background of the card (image, logo, solid block color,..). Very often, the type of used inks is U.V. due to their good adherence to plastic material and also for their easy to use characteristic. The offset printing equipment are very similar to the conventional press that is already used in the paper industry, except for the card produced by injection molding. In this case, the equipment used is still based on the offset technology but the card handling is designed for a card-by-card format.

On both flows, during the embedding operation, the chip or micro-module is inserted and glued in the cavity that has been made by injection molding or milling.

The personalization is the process during which a smart card is modified in order to contain information for one person. Electrical personalization modifies the information in the card chip. Graphical personalization modifies the visual aspect of the card (holder's name, photograph). The equipment used for the graphical personalization are mainly based on a thermal transfer, dye sublimation, monochrome continuous ink jet, embossing and laser technologies. The personalization also includes sometimes the mailing operation.


*Figure 2. Personalized Smart Card*

Finally, the packing of cards, individually or in batches, using blister wrap or other format and materials.

## Manufacturing Performances

Today, the performance of the manufacturing line using the flow described before is good for large batches of cards (more than 40,000 cards/batch). The response time and the cost per card are compatible with this market, based on high volumes of the same product.

However, for the batches that are less than 40,000 cards, the cost per card and the delivery time are not well adapted, and for a small number of cards (2,000 cards) per batch, they are absolutely not adapted. Today, the total smart card market is more and more oriented to the medium, small and very small batch of cards.

We are facing the problem of large volume production where each product can be, however, different, personalized, customized and unique.

After the analysis of different manufacturing flows, the bottleneck is located at the printing and personalization processes.

Traditional offset printing requires film, plates, specialist and substantial press setup time. A typical job takes about four to eight hours in order to set up equipment capable to print 20,000 cards/hour. This doesn't give to card issuers the opportunity to print multiple card designs in a single run. Typically, conventional press run starts with stabilization period, where tens or hundreds of impressions are wasted until the machine stabilizes. With a short run printing, stabilization runs mean important waste percentages. For example, for 3,000 cards job, the stabilization run of 1,000 copies means 33% waste. Traditional offset printing technology is not simply economical or practical for runs under 40,000 cards.

Graphical smart card personalization is based today on technologies that are limited in terms of speed. The maximum achievable throughput is 3,000 cards/hour using continuous ink jet or laser but with a limitation (small and very simple marking information). Very often, the equipment throughput is related to the number of information printed during the graphical information. For example, a laser personalization requires 0.7 second for two lines of characters, 3 to 4 seconds for a barcode and 20 seconds for a black & white photo. If the personalization requires color photography, the used technology is the dye diffusion thermal transfer and in this case, the printing time of an identity photo requires 35 to 50 seconds.

The throughput is dramatically related to the complexity and the type of printed information. One more thing concerning graphic personalization is the fact that we are using different types of plastic and the used printing technologies are not sometimes compatible with all types of plastic. These constraints are not easy to manage into a production flow.

For a short run of card (< 40,000 cards) we can sum up the situation as follows :

- the setup time of the conventional offset press is too long and complex (either for card-by-card or sheet press).
- the cost per card is too high versus customer needs.
- the personalization equipment throughput is too dependent on the quantity of printed information and also limited by the type of used plastic.
- printing and personalization processes are two different processes carrying out very close function but on different equipment.

**What Smart Card Manufacturers are Looking For**

It's clear that today printing and personalization are very close and will merge in a near future. The next generation of equipment expected by the smart card industry will be able :

- to print all information necessary on the card, including the background and the personalization element simultaneously.
- to print the both sides of the card in automatic mode.
  - to personalize electronically the chip or micro-module during the printing operation, in order to assume the right link with the graphical information.
- to use a flexible technology in order to address the different types of plastic card body.
- to have a competitive printing cost per smart card comparing to other technologies and that is quasi constant versus the batch size, including consumable, yield, setup time and equipment amortization.
- to use a Non Impact Printing technology able to print without any physical contact with the smart card and more precisely with the chip or micro-module, in order to have the possibility to print a white card that is already embedded. This new approach will significantly modify the manu-facturing process, especially for the molded card.
- to have a throughput of around 3,000 cards/hour including printing, personalization (electrical, graphical) and fully independent on the quantities of printed information.
- to be easy to use without any specialist in front of the equipment.
- to be connected with a network to the graphic studio (pre-press), manufacturing supervisor and other e-connections.

All the technologies are now or will be very soon available in order to address this equipment specification.

## Which Technology to Choose ?

During the last 5 years, digital techniques have become extremely important in the graphic arts industry. All sections in the production flow for producing multi color printed products are influenced by digitalization. The focus is put on high quality multi color printing, together with high productivity. All big actors in this field are trying to propose to their customer a digital press, mainly for the paper industry.

For the plastic card industry, no solutions have been developed and this was the starting point of the Gemplus development.

Based on this experience and after several benchmarks between the different available digital technologies, we decided to select the piezo ink jet drop on demand technology for the following reasons :

- the very good acceptance of different types of inks and viscosity
- the possibility of high frequency ejection
- no physical contact with the printed substrate
- the good reliability
- the progress curves (technical and economical) are significant every year

## Print head

Several print heads from different suppliers have been tested and the final choice has been made for the Spectra print head. A specific and proprietary development has been carried out for the Gemplus application, based on the Galaxy architecture :

| | |
|---|---|
| Number of jets : | 256 |
| Resolution, X and Y : | 600 dpi |
| Jet spacing : | 0.010” |
| Frequency : | 24 kHz (1 m/s linear speed) |
| Drop mass : | 16 nanograms (ng) |

## Inks

In order to have a good adhesion on the plastic substrate the choice was done on U.V. inks which have the big advantage to be more stable inside the print head and available with different colors.

There have been several aspects of the ink properties that have received special attention by the groups formulating and groups testing the inks during the development:

- Ink Flexibility
- Ink Thickness
- Ink Pinning
- Pigment Loading
- Light Stability
- Adhesion
- Superficial Tracks

SunJet inks have passed the Gemplus ink properties testing. It is important to underline that these inks don't require a specific pre treatment of the substrate which is a significant cost reduction on the equipment. In addition, the electronic components embedded into the plastic card are not stressed.

| | |
|---|---|
| Viscosity | 12cPs ±1 @ 50°C [Brookfield Spindle18, 100rpm] |
| Surface Tension | 25 ±2 Dynes/cm |
| Filtration | SunJet standard filtration tests |
| Settling | No pigment settling after 1 month at Room and Jetting temperatures |
| Shelf Life | 12 months |
| Toxicity | No worse than "Irritant" |

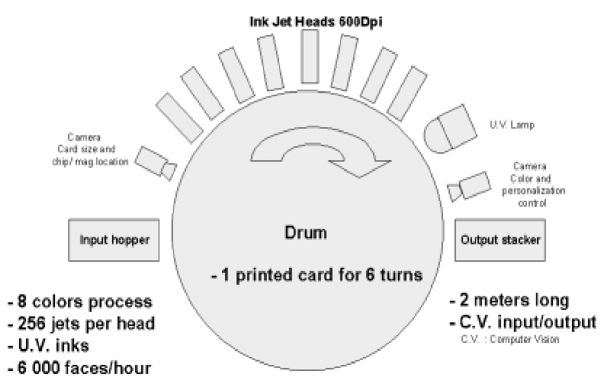


*Figure 3. Printing Process Concept*

## Printing Process

The selected printing process is based on the use of 8 base colors some of which are overlaid in order to create intermediate colors. This technique requires that particular attention be paid to the coalescence phenomenon that arises between drops of different colored ink. In fact, when these ink drops are overlaid or even placed side by side, the drops either mix or are attracted to each other. The consequences of these uncontrollable phenomena are; the introduction of color distortion and bad definition of printed designs. In order to remedy these undesirable phenomena, we make use of a patented method that freezes the drop just after it is deposited with low power U.V. radiation after each printing head. After being subject to this treatment, the ink drop surface solidifies and is ready to receive another drop without any risk that the two drops will intermix or be attracted to each other.

## Equipment Design

Equipment design is illustrated in the diagram below, the equipment features a set of systems and sub-systems to create a machine with a plastic card printing capacity of 6,000 faces/hour or 3,000 cards (two faces)/hour, with photographic quality. This equipment was christened POP (Print On Plastic).

**The equipment operation procedure is as follows:**

Cards from the "White Card Stacker" are first routed to the "Card Reader" electric contacts to be electrically customized. Depending on the results of this customization, cards are then either routed to the "Recto Buffer" if no problems were encountered during customization or, to the waste bin if problems were encountered.

When 36 cards have been loaded into the "Recto Buffer", cards are transferred to the "Loader", the main function of this equipment is to place the cards on the "Drum" at high speed. The "Drum" has a 36-card capacity, cards are distributed over its periphery, it uses a suction system to hold the cards in position during the revolutions (6 revolutions) required to complete card printing.

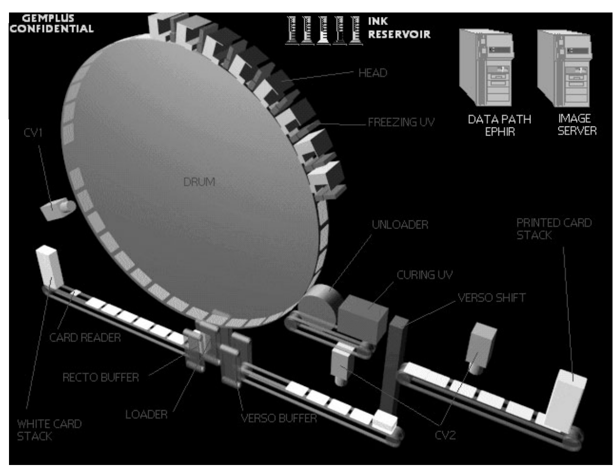


*Figure 4. Equipment Design*

During the 6 necessary "Drum" rotations, the printing heads "Head" and the "Freezing UV" that are installed on a common support, move to sweep the entire surface of the cards to be printed in order to deposit inks and perform surface freezing. Upon completion of 6 revolutions, the "Heads" and "Freezing UVs" are brought back to the start position and the cards on the "Drum" are unloaded by the "Unloader" that places the cards on a conveyor belt. The conveyor belt carries the printed cards under an ultra-violet reticulation lamp "Curing UV", in order to definitively dry inks on the card surface. After being dried, cards may then be directed either to the machine output if only one face of the card is to be printed, or towards the "Verso Shift" that is designed to introduce cards already printed on one face onto the "Drum" to allow printing on the other face, by means of the "Verso Buffer".

Upon completion of either solution, the cards are routed to a printing quality control station. This station decides if the obtained result is correct with respect to a reference image pre-recorded in the control system.

The "Verso Shift" and "Verso Buffer" path features a similar station in order to eliminate or even stop equipment early enough if one or more bad card is detected. Finally, good cards are stored in an output magazine, the "Printed Card Stack".

In the single card face printed scenario, calculations indicate a rhythm of 6,000 faces/hour compared to 3,000 cards/hour when both faces are printed. The "Drum" speed is therefore 1 m/second.

Scrap bins are incorporated into the line in order to recover cards with some fault types, for example:
- electrical fault during electrical customization,
- graphic quality fault during recto or verso printing.

Faulty cards are replaced by colored cards that can be recognized and exchanged for good cards by the operator, after having been regenerated.

A white or colored card loader (not the same as scrapped cards loader) is used to separate batches within a card stack. Separating cards may be printed by the machine to hold information pertaining to the batch in process, for example:
- batch number
- the number of good cards
- the number of bad cards
- the manufacturing date
- the customer references
- the machine number
- the operator name
- etc.

The equipment created is illustrated in the photo below.

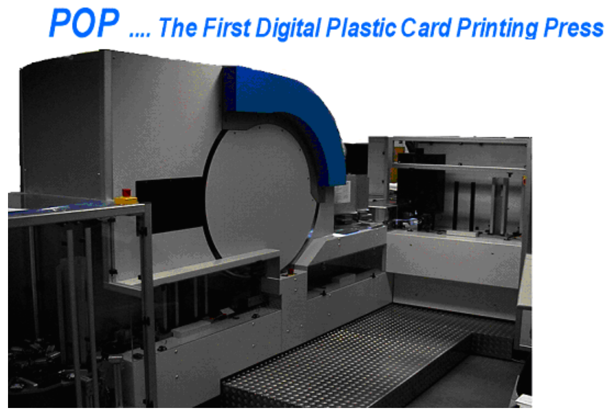


*Figure 5. Equipment photo*

## Results in Production

In order to validate the performance of our prototype in an industrial context, we invited some of our customers to act as Beta Customers, and as such to place orders for prepaid calling card-type telephone cards, printed by the P.O.P. machine, that were put into circulation in the field.

We received a total order for 100,000 cards with specific logos and varying levels of complexity. We manufactured the cards in a production context and implemented numbered indicators in order to measure our equipment's performance.

This production simulation allowed us to refine and finalize the costs per card using P.O.P. technology. We then compared P.O.P. costs per card with costs per card associated with conventional technology implemented at Gemplus, that is to say, offset.

We also performed an in-depth analysis of the repercussions of the various components that make up the final cost of the printed card (labor, ink, etc.), in order to complete these comparisons.

The basic hypotheses used for cost calculation are as follows:
- Printing 100 % of the surface on which the chip is inserted and 60 % of the reverse surface
- Machine depreciation over 5 years
- 98 % yield
- 80 % MTBF
- 4 teams
- Set-up time = 15 min

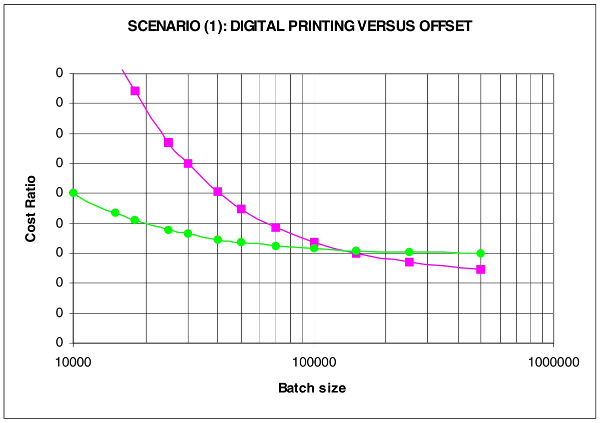


*Figure 6. Cost analysis*

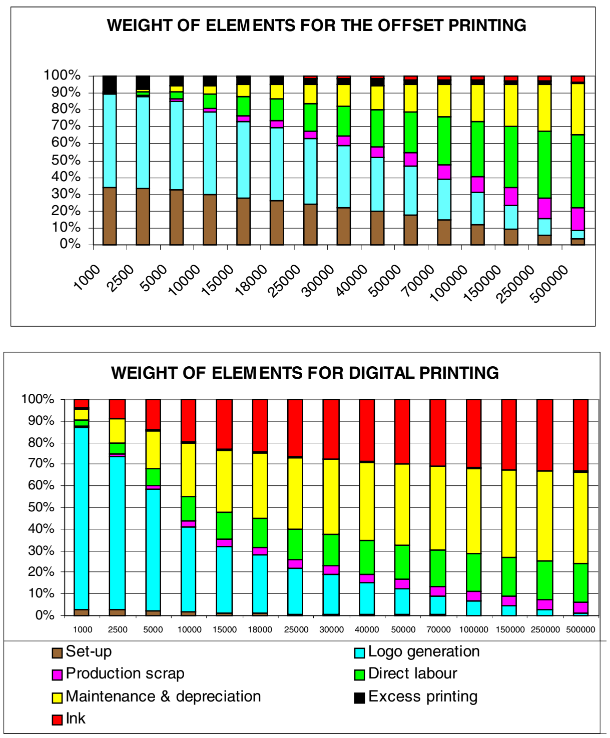


*Figure 7. Cost comparison*

We may observe that costs per card representative curves for both technologies intersect at a batch size of 150,000 cards. Above this number, there are still costs per card differences but these are quite low. On the contrary, for batch sizes smaller than 150,000 cards, the cost deviation is higher and increases with decreasing batch size (for 2,000 cards, costs are halved!).

Given that the current trend is for increasing numbers of cards produced with decreasing average card batch size every day, this is an extremely important point.

In order to refine the analysis of the impact of the various costs per card elements, we have represented the weight of the main cost elements on the graphs below, for both technologies

By comparing these two curves, the sensitivity of digital printing to ink cost, maintenance and equipment depreciation is extremely evident. Ink cost is currently quite high due to the small volume used and the innovative nature of this ink. It is clear that the more ink consumed, the more ink costs will drop significantly (threefold decrease). Ditto for that which concerns the maintenance fraction that covers the costs for changing all the heads once a year, this currently corresponds to a significant sum due to the unique and specific character of these heads. Here also, it is evident that this type of head could be used in other printing applications (CDs, label, textile, etc.) this would result in cost reduction induced by the mass production effect.

## Conclusion

Despite the daring nature of this project and the technical challenges encountered, the results obtained met GEMPLUS expectations. The next step of this project will involve industrializing and introducing this equipment, and also this technology, on the various GEMPLUS group production sites.

Thanks to this development, we will be in a position to target new markets in addition to those we are already familiar with. We could even take the analogy of an iceberg, the visible fraction of this technology's possibilities corresponds to initial expectations but the hidden fraction of this iceberg, which as everybody knows is five times larger, allows us to predict that it will have applications that are currently unimagined and in other areas of activity like CDs, labels, etc.

A significant evolution, revolution is coming and will change the manufacturing approach, organization and probably, the smart card and others market.

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## Biography

Paul Morgavi is working at Gemplus since 14 years and is today Manager of the Manufacturing Equipment Department, part of the Gemplus R&D division. Since 1988 he has worked on the development of Printing Technologies and associated systems. His background covers the technologies like offset, thermal transfer, dye sublimation, laser and ink jet, applied on plastic materials. In 1996, he has worked in the U.S. in collaboration with an American company in order to develop a color plastic card printer using dye sublimation technology. Since 1997, his group is focused on the Digital Color Printing Press for plastic card development based on the inkjet technology. Email: paul.morgavi@gemplus.com