PROJECT FINAL REPORT

Grant Agreement number: 246450

Project acronym: MOLD4PRODE

Project title: Mold for Productivity Enhancement

Funding Scheme: NMP-2009-4.0-5 - Innovative and knowledge-based tooling industry

Date of latest version of Annex I against which the assessment will be made:

Period covered: from 01/01/2011 to 31/12/2013

Name, title and organisation of the scientific representative of the project's coordinator[1]:

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement .

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [3]:

  X has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ Has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable

  X is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Valérie FREREJEAN

Date: 6/05/2014

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

[3] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

1. Executive summary

The constant demand for diversified/personalized goods leads to decrease time-to-market, and to plastic injection moulds with smaller batch production, with no stock. This generates huge productivity losses in the moulding industry:

- Tool Tuning is too long for tool makers before delivery of molds.
- New production run set-up time is too long and generates too much scraps, due to different "operator and machine" parameters.

Many approaches are currently adopted to reduce mold design and production time, but none of them addresses directly the parts productivity enhancement, where "trial error" is still the most employed engineering approach. The innovative approach of Mold4ProdE was to develop and assess a methodology to tool makers, for them to propose and deliver quicker "turnkey intelligent molds", to clients with a reasonable extra cost, and offering them significant productivity enhancement.

The main purpose of the project is to:

- optimize the number and position of sensors in the mold via a knowledge approach, and also via the development of a virtual approach OSLO (Optimal Sensor Location) (WP2)
- implement and assess the concept "Mold Signature" by using the data driven models, built from experimental data collected during production runs with sensors embedded in process equipments (WP3).

These 2 points have been achieved by two different ways, the first based on experience via the implementation of a Knowledge Base System, the other via a complete virtual simulation approach. It aims at applying modern data mining techniques for modeling polymer injection molding process, based on virtual data coming from virtual sensors implemented in a CAD model of the mold.

Mold4ProdE has also provided dedicated and optimized components for tool instrumentation, data collection and treatment (WP4). The project delivers the basis to efficiently use "intelligent moulds".

The project was organized in 3 successive loops. Each loop Integrates work on the theoretical aspects (RTD Work Packages 2, 3 and4) and work on demonstration cases with an update of the related deliverables.

It means that French, Italian, Spanish and German Technical Center have managed 3 different cases during the project, so 12 moulds, with 12 different mould makers, have been instrumented, tested and evaluated during the project (WP5).
The assessments of sensors embedded in moulds have evaluated benefits in mould tuning time and mould new production set up time. The benefits on tuning time can reach 30%, but needs trained people on data collection and treatment. This learning curve has been highlighted during the 3 years of the project. On new production set up time, the benefits are quicker and can reach more than 30%.

16 training sessions have been organized at regional level to Mold4ProdE mould makers and converters, to allow them to integrate the approaches developed in the project, and also the existing knowledge(WP6).

This knowledge is collected in 5 training modules available on the project website for all partners of the project. This will help the European mold makers to move to the knowledge based service industry, identified as a key factor to increase their competitiveness.

2. Work performed with the WP by task (up to 5 pages)

WP2: Methodology for optimized sensors implementation in tools (RTD)

Task 2.1: Sensors implementation based on knowledge Based System ASCAMM

In this task, ASCAMM has developed a Knowledge Based System (KBS) for sensor implementation for injection molding as a hybrid system based on Case-based and Rule-based reasoning.

Both standard phases of knowledge-based systems (knowledge acquisition and knowledge extraction) are implemented and accessible though the web of the project (www.mold4prode.org):

The rule-based reasoning process has been defined following the recommendations that exits in the state-of-the-art. Some of them extracted from this project and others from scientific papers. The case-based reasoning (CBR) has been implemented by modelling the cases as a vector of numerical and categorical attributes over which a distance metrics is defined.

Several metrics for the CBR have been implemented. The validation results state that the best metrics are: the Euclidian distance for numerical attributes and the Jacobs' distance for binary and quantitative attributes. The simple sum of both distances for each comparison case base – new problem is satisfactory.

Validations have been performed; the KBS can be the entry point for the numerical simulator implemented in this WP by PEP. Currently, such simulator explores the entire mould surface to find out the most reliable points to put a sensor. This is a very time consuming task that could be reduced is the surface to explore is bounded. The KBS system can provide such boundaries.

Task 2.2: Sensors implementation based on numerical simulation

Optimal Sensor Location (OSLO) is constituted of 3 steps:

- Process features extraction: consists of extracting some characteristics values from injection software simulation potential node results in order to avoid the temporal dimension. Extracted characteristics values are typically: maximum, minimum, average, areas, singular point. These features are defined to deliver the best representation of the process in accordance with the knowledge of people while remaining intelligible.
- Optimal subset calculation: is based on statistic algorithms that enables the extraction of a subset of best features which classify a part according to its quality criteria.
- Optimal sensor combination calculation: Among feature subset, that can represent between 10 to 20 elements, the best combination is statistically found.

During the project, 4 versions of Algorithms have been tested to improve the results. By working on sophisticated feature selection methods and classification algorithm, we managed to build a consistent methodology. The methodology is not mature and continued effort is required to make methodology more robust but first results are promissing. 4 different use cases have been successfully tested with the methodology, so as that methodology gives the best location of sensor to recover data and measures, sensor location will be included into the mold signature definition in WP3

Task 2.3: Practical "mixed" method for sensor implementation

The definition of task 2.3 is focused on the cooperation of the 2 methodologies developed in task 2.1 and task 2.2. The KBS approach is an application that provides easy to use recommendation for the sensor location and type regarding the experience of tool makers. The Numerical approach is a theoretical methodology that provides accurate response to sensor location and type according to product quality specifications. Both approaches have their interest in the mold design.

The mixed approach has been applied on the KIMW cover case. Numerical approach methodology starts with a node selection. Some nodes are used to compute the quality criteria and others are employed to define the possible location of the sensors. In that case, node selection is reduced thanks to the KBS application.

Once selection is made, the OSLO methodology is rolled out. The results on good precision reaches 87% with 2 sensors: a part pressure sensor and a mold temperature sensor. Previously, with the largest nodes selection, good precision attained 93,7%. Here, precision is less high because there are less possibilities of location. Nevertheless, results are acceptable with less computation time.

WP3: Algorithms and software for mold assessment

Task 3.1 Data processing algorithms

The objective was to select the most suitable parameters to define the mold signature concept. Firstly, all partners (ASCAMM, PEP, KIMW, Tekniker, UCBL and SISE) contributed to identify both the key indicators involved during all phases of the whole injection phase that determine the mold signature and the acceptable ranges for each of them. Secondly, a software tool that helps mold makers and converters to make sure that those key indicators are within the acceptable ranges, was developed by PEP.

A product/process quality inspection system was developed during the production phase. A special attention was given to the information obtained from this phase. In particular, feature selection methods to reduce the data dimensionality and classification methods. All partners participate in this task by implementing different algorithms and validating them with real data.

Task 3.2 Molding paramerter optimisation

All partners were involved in the validation of different configurations of the parameters that control the injection process in order to gain the most optimal configuration in terms of accuracy and computational. An in-depth evaluation provided detailed, empirical information on the effectiveness and impact of different model parameters on the performance of the classifiers applied during the process optimising and monitoring phase. The work carried out in these tasks was devoted to complement the mold signature tool generated in the task 3.1; in particular, information acquired both from the cavity of the mold and machine parameters that define the state of the process during the production phase.

Tekniker carried out an independent study which was focused on demonstrated that the data analysis techniques are independent of both the type of sensors used and the type of data acquisition control system (DACS).

Ascamm, in collaboration with the rest of partners, carried out different tests by changing the experimental conditions: different data reduction methods, different configurations,

Task 3.3 Algorithms and related software integration for mold tuning

Two different Data Acquisition Control (DAC) systems were used. Tekniker and SISE analysed the possibility of integration of the algorithms with best performances in these platforms. All partners improved algorithms to gain more speed during both the creation of the model and the diagnosis of the quality of the plastic part.

Task 4.1 Sensors and Data Acquisition & Control Systems (DACS) in molding monitoring

Survey on existing solutions

In this WP the first step was to launch a questionnaire among partners of the project due to the inherent interest of their response since this collective had a significant size and therefore gives relevance to its result.
The questionnaire focused on the following fields: Sensors and validation of the process, Implementation, Digital Acquisition and Control Systems(DACs) and Interoperability attending to the points of interest pursuited by yhis workpackage. This Questionnaire and its results are available at the website of the project.

Analyzed the responses the generated catalogue of sensing technologies focused in the two principal physical variables that affects this process, Temperature and Pressure that were considered by partners the main variables to control the process. The main core of this catalogue then focuses on the industrial state of the art on these type of sensors available in the market but also explores new possibilities in the use of novel sensor to control the process. These results are in form of a catalogue of pressure and temperature sensors.

An extensive catalogue of sensors is provided, taking in to account magnitude to measure, way of measuring, operating conditions, etc. They were considered the main producers of sensors for plastic injection that the industrial partners stated in the questionary. As a result the catalogue is slightly biased towards pressure sensors, since technology for temperature measurements is much more extended and this catalogue only focused on temperature sensors offered by vendors of pressure sensors specific for plastic injection process.

Due to its inherent interest for plastic injection, it was done an in depth study to compare direct and indirect ways of measuring pressure of the process. Indirect sensors placed behind the ejectors have the potential to be suitable substitutes for direct sensor because it does not cause any marks on the pieces. A comparative test study was documented taking into account these two ways of performing the measurements.

To complete the catalogue it was added a study of other sensing technologies. On It, it was analyzed infrared sensors, more specifically it was reported a set of tests done on Goizper with a FOS infrared sensor due to its inherent interest that relays on its speed time response. This reason makes it an interesting process monitoring sensor for the plastic injection.

Also it was analyzed ultrasonics as a sensing technology for plastic injection monitoring. After an introductory explanation of this technology, the sensing options are shown.

To finish with this catalogue, a deep analysis about the status of research of the academia on the molding process was also done. Plastic Injection Molding is an active field of research embracing many different engineering. Different congresses and scientific journals where these works are published are listed. Its complexity and enormous amount of process parameter manipulation during real time production create a very intense research effort to maintain the process under control. The state of the art techniques applied to the process are shown.

Practical implementation of sensors and data transmission

In the catalogue and after presenting the typology of the sensors and the way of performing measurements, application notes are given in terms of good implementation practices on sensor placing within the mold and wiring for the field of injection molding monitoring. This last aspect becomes fundamental to avoid breakages and malfunctioning problems of the sensors used.

The idea of using wireless sensors is very attractive since a mold in production moves from one machine to machine for production or to warehouse for maintenance. With this purpose, data transmission was checked and more specifically wireless data transmission mechanisms were analyzed, focusing on those taking into account data wideband and reliability in industrial working conditions. This technology is very interesting for the monitoring of the mold because reduces the risk of damaging sensory system due to the continuous manipulations that the mold suffers during its life.

Finally it was documented the possibilities that the market offers to condition sensors to obtain their output to be standard voltage or current outputs. A market analysis on possibilities on converting sensor transduction into an electrical signal, this has to be conditioned (filtered, amplified) and acquired by the acquisition hardware.

Data acquisition and processing systems

There are different commercial solutions ranging from specific data acquisition and processing systems specific for molding injection available on the market and several generic purpose acquisition systems. They were analyzed the different plastic injection acquisition systems. Also they were analyzed generic purpose acquisition systems.

To identify potential improvements in existing solutions an analysis of improvements for acquisition systems has been done. A first functional analysis was performed based in the horned animal concept. This analysis was made aimed to help discovering new domain of service and product for plastic injection data acquisition systems in general and the PSP in particular. The PSP system is the equipment that has been used in the different runs by the different type of users included in the consortium. During the different runs made during the project, different partners has been in contact and using this data acquisition systems. In fact, in the three runs the PSP equipment has been used in the different countries, Germany, Italy, France and Spain. In the case of Spain two DACs systems have been used: the PSP from SISE controlled by ASCAMM and the CompactDAQ from National Instruments controlled by TEKNIKER. These different uses gave the consortium a knowledge of these types of equipment that has been used to get an analysis of the potential improvements of these equipments. The interface to get access to the information from the different users of the system has been the email and direct contact with them using the opportunity that the different consortium meetings. This served to get the feedback on the system and from it to extract potential improvements to this equipment in particular. It also serves to extract generic knowledge on what these equipments should offer to end users.

As a result of the brainstorming among partners of the consortium that used the PSP system in the different runs there were pointed a list of improvements to be done to the PSP system in particular and to any DACs in general. The major improvements added to the Win PSP can be classified attending to the main clusters to which it may be useful. For the Quality Engineer (new possibilities on sensor calibration, injection pressure sensor, set up of Indicators page, CSV Export of indicators only). For the operator (improvements on “User Friendly” ness, EasyView – Easy PSP). For the injection expert (bi-material Machine).

Besides the applied improvements a list of potential improvements was also defined. The main ones were the possibility of creating a PVT path and the possibility of integration of detection algorithms.

Task 4.2 Definition and specifications for Molding machine interoperability
For all the four runs four PSP acquisition systems were fully delivered between beginning of July and end of September of 2011. There was scheduled a demonstration of the DACS in front of the four Technical centers in PEP on 12th July 2011.

For all the runs, interoperability with molding machines was solved through a digital I/O interface. The available analogical signals were also accessed with the DAC. Modifications were done on the machines to obtain the signals to interface them with the PSP system. These means 12 runs. One of them was done using National Instruments generic acquisition system, not specific for molding injection.

For this task, the research centres has participated collaborating with the industrial partners to prepare the interface of the PSP system with the injection machines to allow the interoperability of PSP and machine.

Besides the preparation and installation of the systems for the different runs, they were analyzed different machine manufacturers controls. This analysis synthesizes the actual standardization status of data communication accessible to third parties from the control of plastic injection machines. The result reveals that data access is very different from machine to machine, making very complex a common approach.

This analysis describes the different ways of acceding data to plastic injection machines control. Includes a brief description of what different machine producers offers and the different ways to intercommunicate with machines. This data is accessible through industrial buses like profibus, fieldbus, CAN Open,…) or may be available by TCP-IP connection through interface libraries.

It was also analyzed the OPC-UA, a promising standard for the future that may solve the actual disparity of accesses.

Task 4.3 Algorithm integration in selected DACS (data acquisition & Control System)
Industrial monitoring equipment offer simple algorithms to control process that may be efficient for general purpose but that lack for high demanding requirements. For these last cases ad-hoc designed algorithms by academia or by specialized agents are many times analyzed and developed but hardly tested on real production environments.

In the project, two DAQ systems has been used to verify the developments within the project: PSP system from SISE and Compact DAQ from National Instruments.

For the first two runs the PSP process monitoring system was used. In the first Deliverable D4.1 It was introduced this system. This DAC system was selected to be used during the development of the project. There, it was shown a global view of the equipment, its functionalities and how it was prepared for the project, being adaptable to the different needs generated during the expected developments produced under the project. Due to its open structure it will adapt to the future needs when different sensors will be used and when different monitoring and control strategies will be adopted.

Tekniker, as another alternative to the SISE system for data acquisition and algorithm integration, has tested a system composed with National Instruments devices. The objective of this was to analyzed generic acquisition systems and validated them as part of Task 4.1 applied to the analysis of DACs.

The acquisition system is a CompactDAQ rack from National Instruments. The compact DAQ is a modular data acquisition system, available with different buses connections (USB, Ethernet, Wi-Fi), that allows to connect different slots, specially dedicated to different sensors, with the conditioning hardware already included.

This system, due to its industrial characteristics can be used in laboratory and also in a production line.

The compactDAQ rack controls timing, synchronization and data transfer between the acquisition software in a PC and the rack with eight C series modules. Each module is specifically designed for a particular electric measurement, and contains the signal converter, conditioning circuitry in an unique robust construction.
The system works with software developed using National Instruments LabView language. This program records signals from the sensors and stores them in a database.

All these previously cited characteristics make of this system a valuable tool to monitorize processes with good guarantees.

In this task it was planned to analyze the integration of the algorithms developed during the project in these platforms. In the case of PSP since this equipment has been widely described in Deliverable D1.1 the paragraph will start directly with the integration of the algorithm. In the case of National Instrument it will be first introduced the equipment and explained the data acquisition process to better understand the integration process.

It finishes describing the integration of the algorithms developed on Mold4ProdE under WP3 on Data Acquisition Systems. This integration procedure has been solved for the PSP system and for the generic purpose data acquisition system from National Instruments.

Among the result of WP3 two processing algorithms for data processing were selected. The first the PCA (Principal Component Analysis) algorithm was selected to be integrated into the PSP system. This equipment allows the integration of different configurations of the PCA algorithm for quality inspection. Currently, it does not support other classification algorithms. Win PSP integrates these models from PMML files (Predictive Modelling Markup Language) based on Principal Component Analysis (PCA). It was analyzed and designed the integration needs and strategy.

Tekniker, as another alternative to the SISE system for data acquisition and algorithm integration, has tested a system composed with National Instruments devices.

The testing of different machine learning algorithms, gave to Support Vector Machines algorithm the best results. This method has acquired important prestige in the last decade, particularly in bi-class classification problems. This algorithm is a supervised learning algorithm, so for its training, it needs a database with previously classified instances. The SVM algorithm has been integrated in the monitoring equipment used in the research with the plastic injection machines.

The result is a system that offers a solution to integrate new algorithms developed in different ways and in different platforms into real industrial environments for its testing and validation.

For research and algorithm testing, in a first approach, the database generated is processed offline using Matlab, Python or other programming languages. The standard procedure to process the signals and use them for algorithm training and testing, is as follows: Create the database reading online signals and Once the data base is created, in Matlab and for each signal: preprocess data and apply the result of the algorithm.

All the related activity done in this project is conveniently reflected through the four deliverables submitted on this WP.

WP5: Demonstration Case Studies

Task 5.0 Development of User Case Assessment Metrics (UCAM) and instrumented mould assessment procedure.
In the frame of this task, a set of parameters and mathematical indicators was defined constituting the UCAM. It was, initially, proposed by the task leader, discussed among Technical Centres and revised twice to obtain the final version. Its main function and goal has been to establish a common procedure to assess widely different case studies (different applications, moulding materials, part size, mould layout etc.) and, for every case study, it was successful used to this aim giving indications on the benefits of intelligent moulds compared to similar conventional moulds. Both Mould Tuning and new production Setup indicators were included into the UCAM parameters set. Some of the indicators referred to the number of cycles due to complete a certain moulding phase optimization, others considered the time spent to this purpose and others took into account for the costs, directly or directly, involved in the process setting and in the production setup.
Task 5.1 was entirely afforded by the Technical Centres and provided to the whole Consortium as a turn-key tool to be used for assessment.

Task 5.1 User case production of demo moulds and implementation of moulding machine compatibility at the test site.
Over the three years of Project the consortium developed 12 demonstration moulds for the application and experimentation of what is developed in the other WPs.
In particular, the moulds were built in three different runs, one per year of the project in order to apply every possible improvement and learning coming from the previous year of work.
Each run consisted in four moulds developed at regional level, one mould per country (Italy, Germany, France and Spain) by the industrial partners with the aid and supervision of the Technical Centres who coordinated the job. At the end of each run the approach, the development procedure and the results obtained by each country were shared among the whole Consortium and compared to the others.
For each of the case studies, the workflow was more or less uniform including analysis of the application, requirements and specifications, a wide set of simulations to help choosing the best sensor type and location and to give preliminary information about the process and the moulded part quality, mould design and manufacturing, sensors implementation, assessment and elaboration of results following the User Case Assessment Metrics.
Besides the Technical Centres took care of defining, for each case study, the dedicated Data Acquisition and Control System in order to make the system mould-sensors-injection machine suitable to connect and communicate with the PSP and acquisition software developed by SISE. Doing this task, the Technical Centres cooperated strongly with SISE and with their injection moulding machines producers, as well.

Task 5.2 Mould tuning time reduction

This task aimed to evaluate, for each case study, the benefits offered by the Intelligent Moulds in reducing the time and cost required to tune them and make them start producing parts in specs, i.e. at 100% quality.
This evaluation was done at regional level at the Technical Centres facilities and, besides the evaluation of the Mould Tuning phase another big outcome has been the definition of the Mould Digital Signature. It is a set of curves, indicators and, in general, information coming from the machine signals and the sensors signals which identify the system mould-material-part specifications uncoupling from the machine parameters.
In the frame of this task a first economical evaluation of the Intelligent mould could be performed, which considers only the operations to make a new mould working properly and not all the possible benefit coming during the intensive production life of the mould.
In general, every case study showed a small to medium reduction of the mould tuning time. This advantage is explained by the larger amount and the better quality of the information available during the mould and process first setup coming from having a direct view into the mould, compared to the conventional moulding whose only information comes from the outside, i.e. looking at the machine set parameters, and for whom the tuning can follow a pure “trial and error” approach.

Task 5.3 Assessment of new production setting time reduction with intelligent mould
As the Intelligent Mould appears to give a large amount of information, this can be used as guidelines to faster setup New Productions each time the mould is stopped (for maintenance, or production scheduling or any other reason) and, then put again on the machine and rerun.
Once the mould is tuned and the Digital Signature has been built, the operator can very easily resume it in order to get the production conform to specifications very quickly. This results in a strong reduction of the time and cycles required to start the New Production.
As the mould is stopped and restarted many times during its lifetime, this benefit gets a great economic importance for companies.
The task 5.3 aimed to assess and quantify this advantage for each of the twelve case studies investigated. It’s been evident how the reduction in time of the New Production Setup is from medium to large.
An evaluation in terms of costs related to the New Production Setup gave a technical and economical evaluation of the system compared to the conventional injection moulding.

Task 5.4 Sensor implementation Methodology assessment based on user cases demonstration and cost benefits ratio analysis
After having assessed the Mould Tuning and the New Production Setup phases, the Technical Centres compiled, for each case study, the data collected in order to make a global evaluation of the Intelligent Mould approach. At this stage, the evaluation took into account all the investments (i.e. extracosts related to the sensors layout study, choice, design and implementation into the moulds) and all the benefits they are able to provide. A technical and economical global evaluation was performed at the end of each run of demonstration moulds to get indication on what and how could be improved concerning mould implementation and data processing algorithms. The evaluation of each run lead to modification and new releases of the PSP-DACS and the related software by Sise.
In general, by the three years experimentation, it come out that the break-even point (i.e. the balance between initial investments and the time and costs reduction) of the Intelligent moulds were reached after 30 to 40 cycles of production stop and restart, and this value is well suitable with medium-long life production moulds.
Besides, it was evident that the benefits coming from embedding sensors into moulds have, for companies, a learning curve. It means the best results in using sensors can be reached as the designers and the moulding operators get specific skills on moulding with sensors, which generally

they do not have among the European Companies.

WP6: Dissemination, Training, Exploitation and Technology Transfer

Task 6.1: Needs Analysis and Development of Dissemination and Exploitation Plan
As part of the communication and dissemination action for the Mold4ProdE project a Needs Analysis was carried out both internally and externally during the first reporting period in order to ascertain how best to focus the project dissemination activities. Two similar surveys were compiled, a basic one for organisations not participating in the project and a slightly longer one for project partners. The basic survey was deliberately kept short to increase the likelihood of the survey being completed. The surveys were sent out electronically to organisations within Europe. They were emailed to 2,552 contacts and the email was opened by 301 of the contacts. The survey was viewed by 34 of the recipients and a total of 19 completed surveys were returned. The results of these surveys were analysed and included in the Dissemination and Exploitation Plan.

The Dissemination and Exploitation Plan was a living document which was continually reviewed, amended and updated throughout the project. The purpose of this document was to highlight the work already carried out and to outline future tasks. As the majority of tasks related to dissemination and exploitation would ultimately be finalised in the last period of the project, most of the information contained within this report was based on the original plan rather than actual results. The 'Final Report on Dissemination and Exploitation Activities' provides a complete picture of all dissemination and exploitation activities undertaken during the project.

Task 6.2: Dissemination of RTD Results
The results of the project were disseminated in a number of ways as follows:

Project Website
See details below (task 6.3)

Dissemination Material
Dissemination material was created throughout the project and included two posters, i.e. a marketing poster and a more detailed technical poster highlighting some of the early results achieved. These were displayed at various events and also in the partners' reception areas. A postcard was designed which gave a brief overview of the project and this was later translated into French, Spanish, German and Italian. They were distributed at conferences and trade shows and, like the posters, were also made available in the reception areas of partners' premises. In addition, a technical trifold brochure was produced which included details of the project, its partners and results. All the aforementioned material was made available for download from the project website.

Press Releases
In order to promote the project to a wide audience, four electronic mailings were sent to over 13,000 contacts. They covered a number of topics such as:

- Promoting the launch of the project detailing the aims and objectives as well as the partners involved
- Asking individuals to complete the Needs Analysis questionnaire

- Update on the progress of the project
- Information sent to relevant Trade Associations
- Final ezine promoting the outcomes of the project.

All ezines were uploaded to the project website as well as some of the partner's websites, therefore increasing the project audience.

Newsletters

An annual newsletter was published at the end of each year. Both an external and internal version was produced. The external version was uploaded to the public area of the website and gave readers an overview of project progress to date without divulging any confidential information. The internal version was uploaded to the partners' area of the website.

Generic Project Presentation

A generic project presentation was created which contained a non-confidential overview of the project. It was uploaded to the project website in order for partners to use when presenting the project externally.

Task 6.3: Project Website – Operation and Maintenance

A project website was developed early on in the project using the DNN (dotnetnuke) software and the visual appearance of the website was updated part way through the project. The website provided one of the main dissemination/communication tools during the project and facilitated the dissemination of the project results to as wide an audience as possible.

The website consisted of a number of informative 'static' pages. In addition, a 'rolling box' was created for the Home page which listed latest News and Downloads and visitors were able to select any item appearing which would then take them through to the relevant section for more detailed information. The Home page also made reference to the fact that the project had obtained funding under the Framework 7 programme.

A number of other pages were available such as information about the project and its partners and also pages relating to News and Downloads. Non-confidential information released about the project was uploaded to the 'News' section of the website which was updated regularly.

A secure area of the website was created for the sole use of the partners who were issued with usernames and passwords. Partners were able to access this part of the website via the 'Members' tab where they were required to enter their log in details.

This area enabled the partners to:

- Review the information made available to public registered users in the restricted public area
- Access uploaded information about the project in the Consortium Area, including:
    - Legal Documents
    - Financial Information
    - Meeting Information
    - Template Documents

- Access the Work Package areas where they can:
  - Download Documents
  - Upload new documents to share with the other partners

The informative static website pages were made available in all of the project languages: English; French; German; Italian; and Spanish by switching between the various languages using the different flags in the right-hand corner of the screen. The functional pages with minimal text appeared in English.

Task 6.4: Internal Dissemination of Project Results and Regional Workshops
The project results were disseminated internally via the project website and also by way of internal annual newsletters. These newsletters were produced at the end of each year and contained such information as the overall project development and current trends and developments in the field. To further ensure that the consortium was kept fully up to date with the project results, a series of four workshops in four different countries (16 in total) were organised. The purpose of these workshops was to train the mould makers on the use and implementation of the methodology developed in the scope of the project. Each workshop took into consideration new improvements brought to the methodology after each new test run and an overview of each workshop was presented in a series of deliverable reports.

Task 6.5: Training Materials and Modules
Five electronic training modules were produced and covered areas such as demonstration activities like economic advantages together with technical details, they each included a series of questions in order to test the user's understanding of the module. They were based on the knowledge developed during the project and were refined after each series of workshops had taken place. The purpose of these training modules was to transfer the results of the methodology and logistic developments of the mould makers and end users of the projects.

3. Executive summary of the work done by WP (not exceeding 1 page) over the whole project duration

WP2: Methodology for optimized sensors implementation in tools (RTD)

Task 2.1: Sensors implementation based on knowledge Based System ASCAMM

A Knowledge Based System (KBS) for sensor implementation for injection molding has been build as a hybrid system based on Case-based and Rule-based reasoning.

The rule-based reasoning process has been defined following the recommendations that exits in the state-of-the-art. Some of them extracted from this project and others from scientific papers. The case-based reasoning has been implemented by modelling the cases as a vector of numerical and categorical attributes over which a distance metrics is defined.

Task 2.2: Sensors implementation based on numerical simulation

Optimal Sensor Location (OSLO) is constituted of 3 steps:

- Process features extraction: consists of extracting some characteristics values from simulation These features are defined to deliver the best representation of the process.
- Optimal subset calculation: is based on specific statistical algorithm that enables the extraction of a subset of best features which classify a part according to its quality criteria.
- Optimal sensor combination calculation: Among feature subset, that can represent between 10 to 20 elements, the best combination is found

The methodology is promising and continued effort is required to make methodology more robust. 4 different use cases have been successfully tested with the methodology. So as that methodology gives the best location of sensor to recover data and measures, sensor location can be be included into the mold signature definition in WP3

Task 2.3: Practical "mixed" method for sensor implementation

This task is focused on the cooperation of the 2 methodologies developed in task 2.1 and task 2.2.
In that case, node selection is reduced thanks to the KBS application, so the time for calculation can be reduced to provide the best sensors choice and location. The precision is less high, but results are acceptable with less computation time.

WP3: Algorithms and software for mold assessment

The mold signature is an optimised mathematical model obtained from from adequate data processing of signals from mold sensors and injection molding machines. This model represents the acceptable process window of the tool. The mold signature allows obtaining a product quality inspection system. In order to define any mold signature, it is necessary to carry out the following two steps: (1) to monitor online the process by identifying and control those indicators involved during all phases of the whole injection phase, and (2) to inspect offline the quality of products.

Basically, "Process monitoring" phase starts with the identification of key-process variables. Afterwards, each key process variables is then associated to a specific control chart to detect abnormal behaviour (drift, shift, etc). The control chart is completely defined when the targeted value and its control limits are specified. When values are outside control limits, process warnings are emitted to notify the problem to production plant operators. This approach is the standard

Statistical Process Control (SPC) methodology applied by many manufacturing companies. When the number of key-process variable increase and relationship between product quality and processing conditions are complex, standard SPC approach often fails.

This WP is devoted to determine the mold signature and to define a product/process quality inspection system based on information obtained from both sensors inside the cavity of the mold and injection molding machines. The appropriate data processing algorithms were developed to make the necessary on-line measurements, predictions and adjustments to the injection molding machine during a mold proving or production run. This implied to optimise the algorithms in terms of computational time by reducing the data dimensionality and finding the most optimal configuration for the classifier.

WP4: Sensors integration technology and data acquisition and control system

Task 4.1:

A market analysis has been done to identify existing solutions in the field of mold monitoring. On it, it has been identified existing solutions in the field of mold monitoring, either sensors (focusing mainly on pressure and temperature sensors and focusing on the mold) and data acquisition systems,.

It has been reported a catalogue of available sensors and a guide of how they should be implemented.

An exploration on transmission mechanisms mainly those that allow wireless data exchange from sensor to acquisition system.

It has been done a State Of the Art of the research that it is being done by the Academia

Beside the market analysis, the following analysis have been done. Comparison of both direct and indirect pressure measuring mechanism. Potential improvements: Report about the performance of infrared sensors, Report of ultrasonics possibilities for use in mold process monitoring

Data Acquisition Systems: A catalogue of already existing plastic injection specific solutions and non specific systems. About DACs, a functional analysis on improvements to DACs system was carried on, resulting a set of improvements pointed out for the PSP system during the project and potential improvements were targeted for the PSP system that also comprises generic DACs.

Analysis done to search possible improvements to DACs : Improvements done to the PSP during the project: New calibration mold sensor screen and the easy PSP cabinet concept. Improvements targeted: New algorithms integration, the PVT path

All this analysis and reviews are documented in Deliverables D4.1, D4.2 and D4.3

Task 4.2:

For the different runs, the interoperability with molding machines was done through digital I/O interface and with the access to available analogical signals of the machine. For this purpose, modifications were done on the machines to obtain the signals to interface them with the DAC system.

Also the actual status of industrial interoperability with the machine control has been analyzed and reported (D 4.4). It covers: Real time industrial buses: Fieldbus, DeviceNet, profibus,…, Non real time data access: OPC, ODBC,… Coming standards: OPC-UA, ..In fact a big dispersion between the different manufacturers has been found, making it difficult to make a general approach. New standards like OPC UA may solve this problem in the future. This standard is reported in the deliverable.

Task 4.3:

For the algorithms integration the following DACs have been used on the project: PSP System: It has been used in all runs except the third Spanish run. It has been developed a new data acquisition system for the 3rd run. The National Instrument Compact DAQ that has been used by Goizper and Tekniker for the 3rd run due to its versatility and capacity to integrate different types of sensors.
It has been analyzed the feasibility of integration of developed algorithms on WP3. More specifically it was detailed the integration procedure for the two algorithms tested and selected in WP3. The Principal Component Analysis (PCA) algorithm is already integrable in the PSP. The Support Vector Machine (SVM) is easily integrable in a laptop connected with a CompactDAQ DAC from National Instruments.

WP5: Demonstration Case Studies

Development of twelve demonstration case studies (trhee runs of 4 moulds, one per country) to apply and assess all the R&D work in terms of sensors selection and identification (type, position, mounting scheme ecc.) and sensors usage in injection moulding.

The twelve demonstration mould were built by the industrial partners of the Consortium with the help and supervision of the Technical Centres, responsible of the job at regional level.
Many activities related to the demonstrators running were performed entirely or partially by the Technical Centers in strict cooperation with the involved industrial partners. Among these: analysis of the case study and the application, choice of the moulding material, quality specifications and requirements definition, moldflow simulations for the sensors layout and implementation definition, machine compatibility analysis of the Intelligent Moulds and interfacing between IMM and DACS-PSP, mould assessment.

The assessment carried out in the most uniform and comparable way included:

- Mould Tuning phase assessment and evaluation of reduction of time and costs for this phase;
- New Production Setup phase assessment and evaluation of reduction of time and costs for this phase;
- Global evaluation of the Intelligent mould considering also investment costs and cost reduction allowed by the use of sensors.

The assessment of each case study was under the responsibility of the regional TC but the coordination of all of them, the data collection and global elaboration were shared at the end of each Project here with the whole Consortium. As well, the results obtained at the end of each year were used to apply modification and improvements to the M4PE Intelligent Mould implementation procedure and to the hardware and software dedicated devices. This sharing lead to new releases of the device by SISE according to the technical Centres advices and requests.

WP6: Dissemination, Training, Exploitation and Technology Transfer

Dissemination is necessary in order to exploit the results of the project to as wide an audience as possible and to raise public awareness of the project, its expected results and progress using effective communication means and tools. Various tools were used for this purpose throughout the lifetime of the project, starting with the creation of a project website which was updated on a regular basis. As well as containing information about the project, news stories and downloads, the website also included a secure partners’ area which acted as a means of communication between the partners enabling them to share information between work packages. Following this, a number of dissemination materials were produced including two project posters (one marketing and one technical), A postcard translated into various languages, i.e. English, German, French, Spanish and Italian, a technical trifold brochure and a generic project presentation. All of these were used to disseminate the project at various conferences and trade shows and were also uploaded to the project website. Furthermore, four ezines were sent out to over 1,300 contacts and three newsletters (both internal and external versions) were produced.

A Dissemination and Exploitation Plan was created and this living document was reviewed and updated on an ongoing basis as the project developed. The purpose of this document was to highlight the work already carried out and to outline future tasks.

A series of 16 training workshops took place in four different countries. These workshops were organised by the National Leaders to present the results and train the national partners (in particular the mould makers) in the use of the results. Each session took into consideration new improvements brought to the methodology after each new test run and an overview of each workshop was presented in a series of deliverable reports.

Five electronic training modules were created and uploaded to the project website. These modules included key information such as demonstration activities like economic advantages together with technical details and included a series of questions at the end to test the user's understanding of the module.

A Needs Analysis was completed and reported on during the first reporting period in order to ascertain how best to focus the project dissemination activities. The results of these surveys were analysed and included in the Dissemination and Exploitation Plan.

Finally, five results were identified which can be exploited by the partners within the consortium but no patents or other IPR licences will be applied for.

4. Summary description of WP context and objectives (not exceeding 1 page).

WP2: Methodology for optimized sensors implementation in tools (RTD)

The main objective of the Mold4ProdE project is to develop and assess methodologies that help tool makers deliver quicker ‘turn key intelligent’ tools to end users. These tools will allow: (1) selecting the most proper type of sensors and the best location inside the mold, and (2) providing optimisation algorithms for each phase of the whole injection molding process. This addresses the mold signature and holds significant benefits for increasing productivity, cost/scrap reductions and improved quality of the resulting part.

WP2 has been carried out in parallel with WP3 in order to provide a global solution for sensors implementation in injection moulds. The common goal of WP2 and WP3 is to converge together to a practical definition of “mould signature” associated to the concept of intelligent turn-key injection mould. To look for a solution to optimal sensor implementation problem, two ways are considered.

- The first way is based on knowledge approach. This approach consists in accumulating knowledge to build a relevant use cases database and to provide tools to exploit it. The objectives of this first period were to built, test and provide a first implementation of the Knowledge tool.
- The second approach consists in exploiting numerical simulation tools (polymer injection moulding simulation software) to define numerically the best sensor configuration. The objective of such an approach is to provide information on sensors location at early stage during the development of the mold.

WP3: Algorithms and software for mold assessment

This WP contributes to the project challenges by:

1. Broadening the conception of mould signature to address current industry needs, and then describes some needed developments to convert that vision to reality. This vision pull together the whole injection moulding story, that is, the big picture, integrating existing fragmented ideas of machine, material, process, production and information control with the development of tools to produce a fully optimised manufacturing strategy. In this paradigm, each phase of the whole process will have consistent setup/optimisation procedures. The main objective is to provide a specific direction for improving product quality during the whole life cycle of the product: from the design to the production. A general scheme of the whole injection moulding process was defined and a software application was created in order to help mold makers and converters to know what information is necessary to gain a feasible mold signature definition.

2. Providing optimised algorithms and mathematical treatments for data processing in order to build a predictive model capable of detecting the quality of the molded plastic part. The predictive model calculates the mathematical distance between the related processed data and the mold signature. The creation of the predictive model needs to gain the following specific objectives:

- Decide what variables characterise the process (data collecting).
- Data dimensionality reduction.
- Selection of the best variables (best predictors).
- Building the predictive model.
- Evaluate the quality of the model by using different indicators.

Different existing data-driven modelling approaches were analysed and adapted for this specific problem. The predictive model was built by using real data collected during production runs with sensors embedded in process equipments.

WP4: Sensors integration technology and data acquisition and control system

The WP4 is devoted to the identification of existing solutions in the field of mold monitoring, either sensors and Data Acquisition and Control System systems, as well as the identification of best practices in deploying those solutions and the implementation of algorithms developed in WP3.

The main objectives are:
1. To create a catalogue of sensing technologies and good implementation practices in the field of injection
molding monitoring
2. To identify potential improvements in existing solutions
3. To implement the algorithms developed in WP3 in a real processing unit

According to these objectives, the WP4 is split into 3 main tasks:

Task 4.1 Sensors and Data Acquisition & Control Systems (DACS) in molding monitoring
Sub task 4.1.1 Survey on existing solutions
Sub task 4.1.2 Practical implementation of sensors and data transmission
Sub task 4.1.3 Data acquisition and processing systems

Task 4.2 Definition and specifications for Molding machine interoperability

Task 4.3 Algorithm integration in selected DACS (data acquisition & Control System)

WP5: Demonstration Case Studies

The WP5 moves from the necessity to evaluate and to test the M4PE approach that is developed, mainly, in the frame of WP2, WP3 and WP4.
Several aspects were developed in those workpackages from the implementation of a standardised methodology for choosing the best sensors configuration (based on knowledge, experience and software simulations) for developing the electronic devices for acquisition of the information and the software for its mining and elaboration.

The intent of the real experimentation is to practice the global approach and assess what are the main outcomes from real cases.

The main interest for the Consortium is acquiring experience and data about Mould Tuning time reduction (mainly addressed to mould makers) and about the reduction in time for the Setup of a New Production (of main interest for end users).

A powerful tool that links the job of the mould maker to the end-user is the definition, at the stage of the Mould Tuning, of the Mould Digital Signature which can be provided by the toolmaker and used by the end user each time he run a production.

Finally, the economical evaluation of the Intelligent Mould is addressed to all the partners and is the key point to tell if the approach is successful or not.

WP6: Dissemination, Training, Exploitation and Technology Transfer

The purpose of the work package was to ensure the project was disseminated to as wide an audience as possible by various means including the use of dissemination material developed during the project and also through a number of training sessions. These training sessions were used to pass on the technical knowledge to SMEs throughout Europe in order to ensure that they were fully conversant with the advantages of the productivity enhancements of intelligent moulds.

During the project, it was necessary for the technical centres and mould makers to work together in order to become familiar with the new technologies and techniques developed in the project.

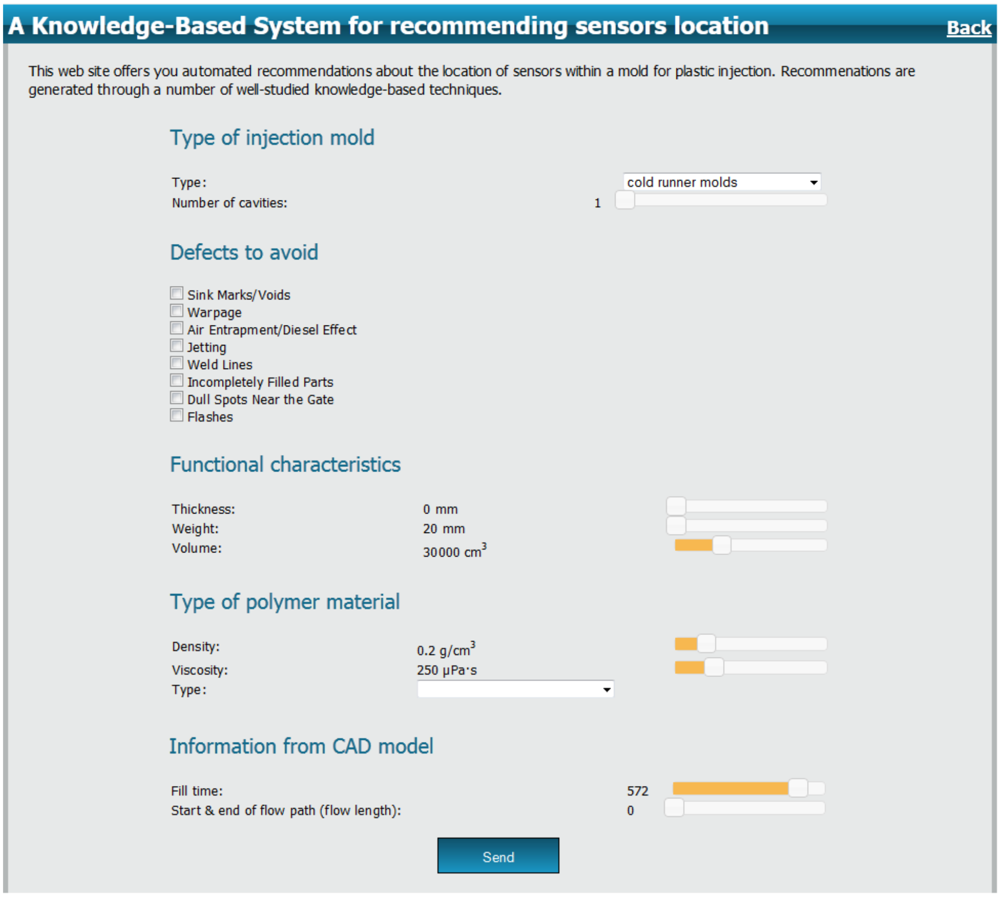
Lastly, plans and procedures were implemented to enable the technologies developed to be effectively exploited.

5. Description of the main S&T results/foregrounds generated by the WP (not exceeding 5 pages)

WP2: Methodology for optimized sensors implementation in tools (RTD)

Knowledge Based System (KBS) for sensor implementation for injection molding has been developed as a hybrid system based on Case-based and Rule-based reasoning.

Both standard phases of knowledge-based systems (knowledge acquisition and knowledge extraction) are implemented and accessible though the web of the project (www.mold4prode.org):



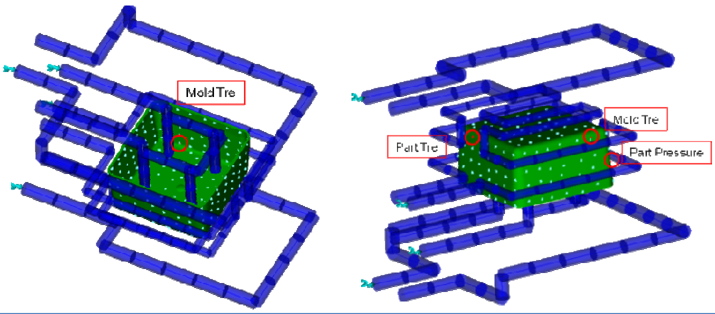
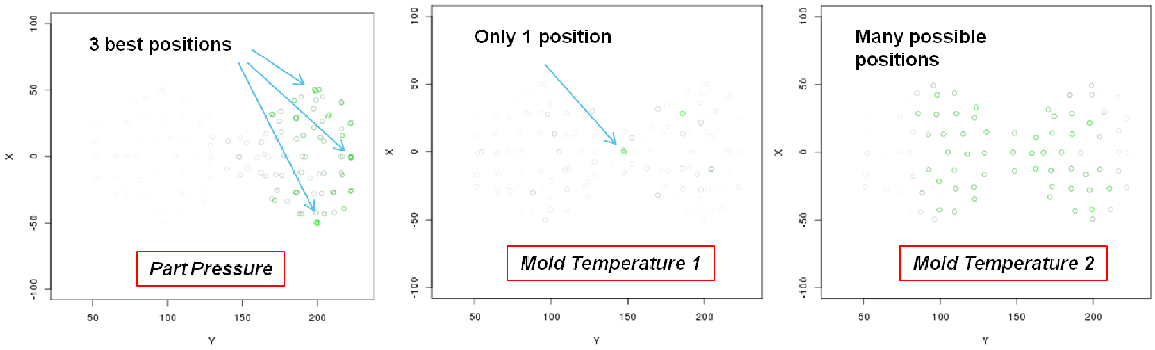
The rule-based reasoning process has been defined following the recommendations that exits in the state-of-the-art. Some of them extracted from this project and others from scientific papers. The case-based reasoning (CBR) has been implemented by modelling the cases as a vector of numerical and categorical attributes over which a distance metrics is defined.

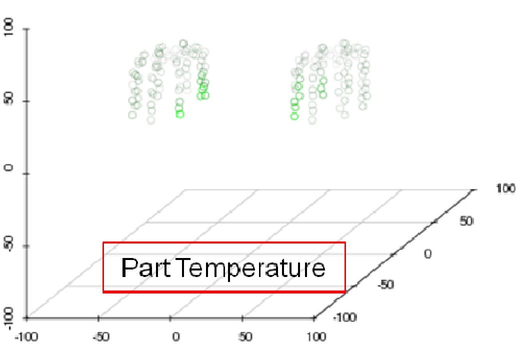
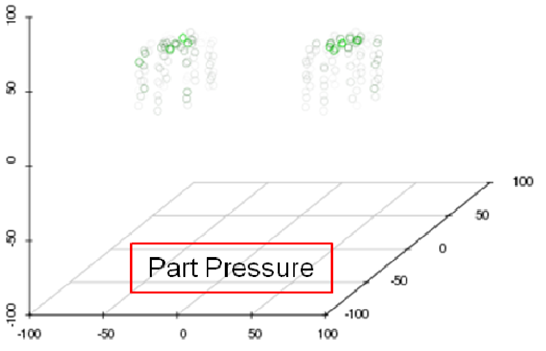
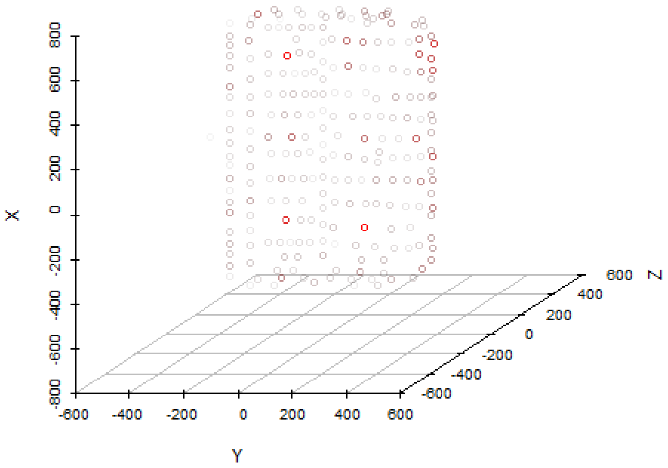
We have implemented and tested several metrics for the CBR. The preliminary validation results (done internally) state that the best metrics are: the Euclidian distance for numerical attributes and the Jacobs' distance for binary and quantitative attributes. The simple sum of both distances for each comparison case base – new problem is satisfactory.

A user web guide of the web based application has been developed. The guide described the two different web-based applications: to acquire knowledge from experts (only accessible from the website of the project) and to give recommendations to end-users (http://mold4prode.ascamm.com/kbs.php#results):

In parallel, a virtual methodology for Optimal Sensor Determination OSLO) has been developed in 3 steps:
- Process features extraction
- Optimal subset calculation
- Optimal sensor combination calculation

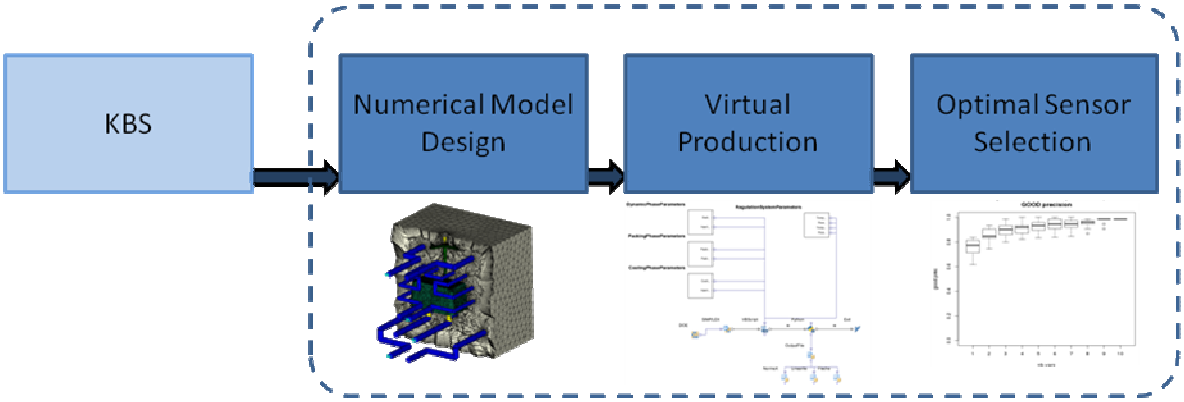
During the period, 4 versions of Algorithms provides by UCBL have been tested to improve the results. The different use cases tested with the methodology are summarized below

<table>
<tr><th></th><th>Number of sensors</th><th>Type</th><th>Good Precision</th><th>Comments</th></tr>
<tr><td>BOX (PEP)</td><td>4</td><td>2 Mold Temperature sensor
1 Part température sensor
1 Part Pressure sensor</td><td>100%</td><td>Surface Result are not satisfactory</td></tr>
<tr><td colspan="5">
</td></tr>
<tr><td>HCOVER (KIMW- KM)</td><td>3</td><td>2 Mold Temperature sensor
1 Part Pressure sensor</td><td>93,7%</td><td></td></tr>
<tr><td colspan="5">
</td></tr>
<tr><td>CAP (ASCAMM-Matrix)</td><td>2</td><td>1 Part Temperature sensor
1 Part Pressure sensor</td><td>91%</td><td></td></tr>
</table>

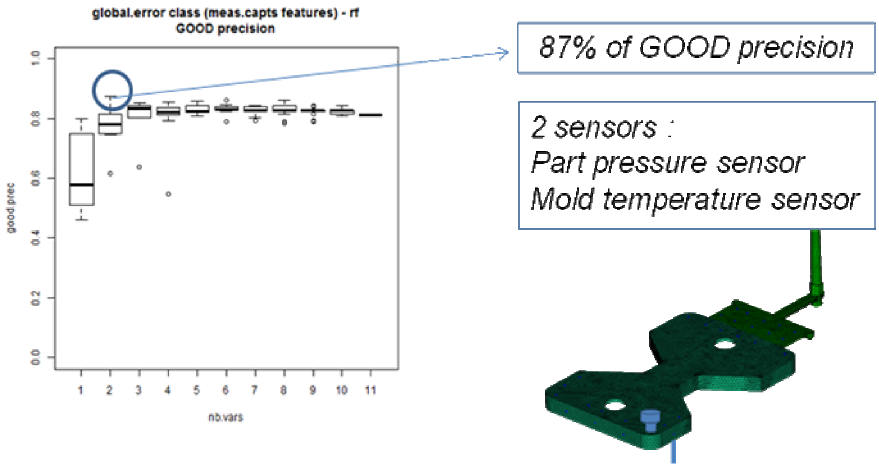
				
Tank (PEP-Compose)	3	3 Part Pressure sensor	97.4%	
				

Depending of the case, it is possible to predict the position of 2 to 4 sensors (pressure and/or temperature) to reach 91% to 100% of theoretical prediction of geometrical quality of the parts
By working on more sophisticated feature selection methods and classification algorithm, we managed to build a consistent methodology. The methodology is totally new and continued effort is required to make methodology more robust.
Moreover, as that methodology gives the best location of sensor to recover data and measures, sensor location is included into the mold signature definition.

Last efforts have been focussed on the integration of the Knowledge Based System (KBS) with the Optimal Sensor Location (OSLO) system to improve the time of calculation.
KBS was used as a starting point to reduce the computational time of numerical simulations by enclosing the surface of the mold to be analyzed by the numerical simulation tool:



The integration of both methods for sensor implementation was analysed by using a real case, the Hcover (Part of the German first run):



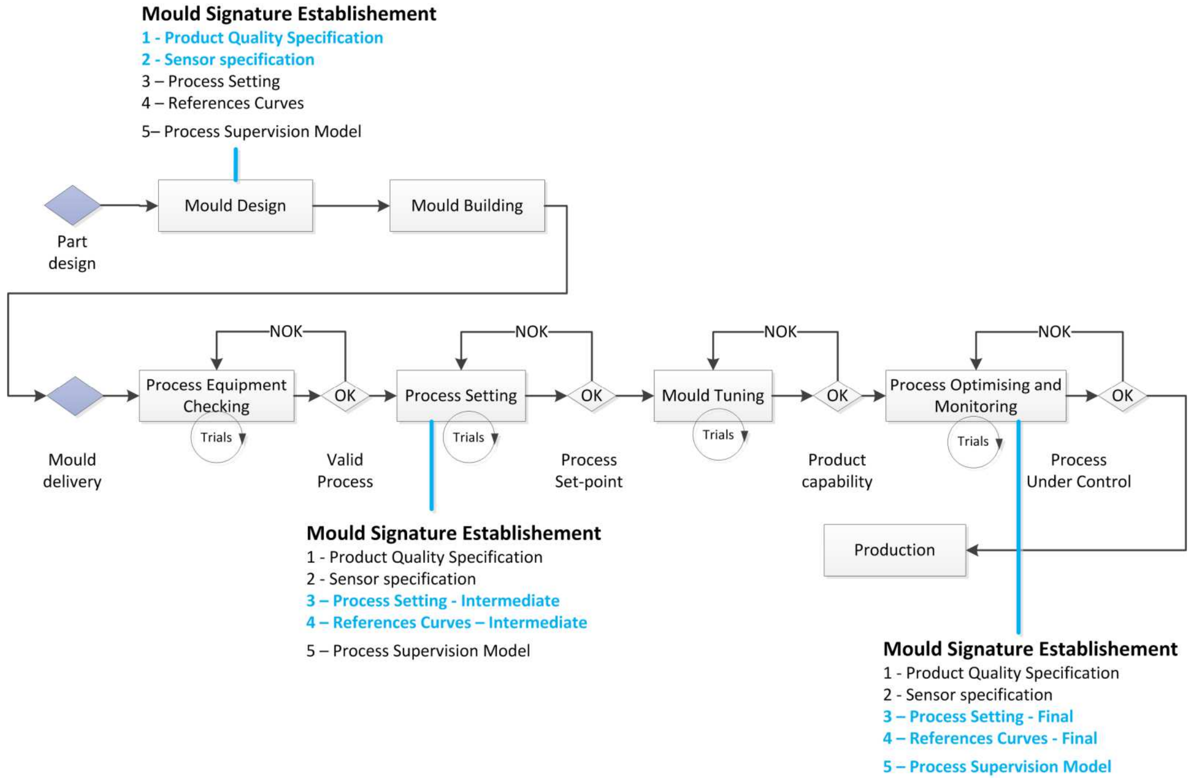
The results on good precision reaches 87% with 2 sensors: a part pressure sensor and a mold temperature sensor. Previously, with the largest nodes selection, good precision attained 93,7%. Here, precision is less high because there are less possibilities of location. Nevertheless, results are acceptable with less computation time.

WP3: Algorithms and software for mold assessment

Motivated by significant progresses done in the field of fault detection and diagnosis of batch processes based on the information directly gathered from sensors, it was essential to investigate if these concepts could be applied entirely to **calculate the mould signature**. In this WP, the mould signature is defined as the ideal configuration of parameters that consistently yield an optimal injection. Here we were especially concerned about obtaining a robust feature set capable of representing the main characteristics that describe major trends in terms of data variability.
The first step was to identify the set of parameters that affect the injection process. We realised that not only parameters involved during the production phase determine the quality of the process. Therefore, the mold signature concept was spread out to all phases involved in the whole injection process since it was detected that a mold signature cannot be defined in a reliable way without guaranteeing that the key information of previous phases are within acceptable ranges. This key information determines the creation of the mold signature.

As a result, a fully optimised manufacturing strategy based on identifying and predicting the best indicators involved during the whole life cycle of the product from the design to the production was described. Since the main causes of defect in injection molding can be because of mould design, process parameters, machine, operator or material, this vision pull together the whole injection moulding phases, integrating existing fragmented ideas of machine, material, process, production and information control with the development of tools to produce a fully optimised manufacturing strategy. In this paradigm, each phase of the whole process has consistent setup/optimisation procedures.

This global methodology provides consistent machine set-up and optimisation procedures through the adaptation of expert knowledge and computer simulation. "Mould Signature Concept" can be defined as a set of information describing moulding conditions (viewed in the mould) required to make good parts. Notions of "mould process set-point" and "mould processing window" have been introduced to specify moulding conditions. The following figure shows the global methodology described:



Special attention was given to the 'process optimising and monitoring' phase since the quality of the final part is identified by monitoring both a number of parameters from inside the cavity of the mold and from the machine. In order to evaluate part quality, we extract a set of salient statistical features given a number of injection moulding process parameters and then match these features against a statistical model of the Normal Operating Conditions (NOC) or mould signature. Deviations from the NOC model are clear indications of process fluctuations leading to part defects.

This work was concerned with applying the techniques and modelling methodologies that have shown a good performance for fault detection and diagnosis of batch processes based on the information directly gathered from sensors. In particular, we present a study that aims to create the mould signature using statistical approaches that reflect the structure of data obtained from sensors within a mould and data obtained from the injection machine. Experiments were carried out in real environments.

A number of statistical methods were analysed in order to build a robust classifier capable of determining the quality of the piece in real time which demands to gain an optimal performance in terms of computation time. As trials demonstrated, the main benefit of using these mold signature tools is to reduce the tuning time and setting time by an average of 15%.

A number of process supervision models were implemented, evaluated and improved. An in-depth evaluation was intended to provide detailed, empirical information on the effectiveness and impact of different model parameters on the performance of the classifiers applied during the process optimising and monitoring phase. This work was devoted to complement the mold signature tool; in particular, information acquired both from the cavity of the mold and machine parameters that define the state of the process during the production phase.

Different classifiers trained on real data obtained from trials were tested in several conditions and their performance was studied. Different approaches based on feature extraction optimisation and best feature representation were proposed for improving the robustness of the decision support system to identify the quality of an injected plastic part. Different ways to extract feature vectors were analysed. Training set sizes were analysed in order to decide the minimum training set size to guarantee a good performance.
According to the results reported, it is possible to conclude that the method based on Standard Deviation can be applied successfully as a data reduction method for each type of sensor. Data from different sensors give most information about the state of the whole injection process which led us to improve the performance of the control and monitoring system.

As a summary, the main Scientific and Technology (S&T) results were:

- A fully optimised manufacturing strategy (new concept of mold signature).
- Software tool to help mould makers and converters control the whole injection process from design to production. This tool helps to define the mold signature.
- Improvement of classification and feature selection techniques in data mining to create a mould signature.
- A predictive system capable of detecting the quality of the plastic part based on information obtained inside the mould and machine parameters.

Interesting insights can be gained from the foregrounds described in this section. These can be summarised as follows:

- Supervised classifiers can lead to successful decision support systems for identifying the quality of the final part.
- Closer to a more realistic problem of classification. Most of tests were carried out with real data obtained from different trials. Furthermore, there was no test data overlap with training data (cross-validation technique was used).
- Not limited to two-class condition classification problem. A seven-class condition problem was analysed. Six different types of defects were identified.
- Assumptions made about injection molding process. Some assumptions about the whole injection process were appropriate in the creation of mold signature; especially, those based on identifying key information.
- Support Vector Machine as a potential classifier.

- Classifiers independent of the Data Acquisition Control System (DAC)s.

There may be several possible directions in which the work presented here could be extended or improved. Some of the possibilities include:

- Increasing the complexity of cases. Since the initial objectives of this work concerned with creating the mold signature, it could be interesting to check the performance of the proposed tools with more real cases.
- Reducing the computational time of classifiers by reducing the data dimensionality.
- Providing corrective measurements when a default is detected. This approach would imply to find the correlation between defects and causes. The Case-Based Approach (CBR) could be analysed for this goal.
- Adaptation of the proposed solution to other manufacturing processes such as die cast.

WP4: Sensors integration technology and data acquisition and control system

The main generated results and foreground obtained from this workpackge, are the catalogue of sensing technologies and good implementation practices in the field of injection and molding monitoring, the identification potential improvements in existing solutions and the implementation of the algorithms developed in WP3 in a real processing unit.

The **catalogue** is an in depth study of the different sensors available for the mold industry, attending to the two principal physical variables to measure, Temperature and Pressure. It was not intended for this catalogue to go beyond the industrial state of the art on applied sensors to the mold in plastic injection processes. This limits the presented catalogue to pressure and temperature sensors.

It has a chapter defining the typology of the sensors as well as the physical principles that explain their way of working.

Due to its inherent interest for plastic injection, there is an in depth study and comparative between direct and indirect ways of measuring pressure of the process. Indirect sensors placed behind the ejectors have the potential to be suitable substitutes for direct sensor because it does not cause any marks on the pieces. A comparative test study is provided in this chapter taking into account these two ways of performing the measurements.

After presenting the typology of the sensors and the way of performing measurements, application notes are given in terms of sensor placing within the mold and wiring. This last aspect becomes fundamental to avoid breakages and malfunctioning problems of the sensors used.

The catalogue of sensors takes into account magnitude to measure, way of measuring, operating conditions, etc. They were considered the main producers of sensors for plastic injection, that the industrial partners stated in the questionary surveyed during the first half of 2011. The criterion was to select the pressure sensors. Temperature technology is much more common and only were selected the temperature sensors offered by vendors of pressure sensors specific for plastic injection process. It also provides guidelines to be able to select a concrete sensor based on concrete needs.

In this catalogue it is included an analysis on infrared sensors, more specifically it will reported a set of tests done on Goizper with a FOS infrared sensor due to its inherent interest that relays on its speed time response. This reason makes it an interesting process monitoring sensor for the plastic injection.

Also wireless data transmission mechanisms are analyzed, focusing on those taking into account data wideband and reliability in industrial working conditions. This technology is very interesting for the monitoring of the mold because reduces the risk of damaging sensory system due to the continuous manipulations that the mold suffers during its life

Also it analyzes the possibilities that ultrasonics has for plastic injection monitoring. After an introductory explanation of this technology, its sensing capabilities are shown.

A deep analysis about the status of research of the academia on the molding process has been also done. Plastic Injection Molding is an active field of research that embraces many different engineering. First, different congresses and scientific journals where these works are published are shown. Its complexity and enormous amount of process parameter manipulation during real time production create a very intense research effort to maintain the process under control. The state of the art techniques applied to the process are documented.

Also a market analysis on DACs is done. Once the sensor converts the measured parameter into an electrical signal, this has to be conditioned (filtered, amplified) and acquired by the acquisition hardware. There are different commercial solutions ranging from specific data acquisition and processing systems specific for molding injection available on the market and several generic purpose acquisition systems. First, it will document the different plastic injection acquisition systems. Then it will document on generic purpose acquisition systems. Finally it has been documented the possibilities that the market offers to condition sensors to obtain their output to be standard voltage or current outputs.

During the project an **analysis of improvements** for acquisition systems has been done. A first functional analysis was performed based in the horned animal concept. This analysis was made aimed to help discovering new domain of service and product for plastic injection data acquisition systems in general and the PSP in particular.

The used functional analysis is an engineering process to generate concept for a system. It is a heuristic approach to identify main actors in the environment, and show interrelations and leads to the construct of result of guideline. The proposed method follows the following steps:

a. Validation of the system.

b. Identification of environment

c. Identification of functions

d. Characterization of functions

In the project, two DAQ systems has been used to **integrate** the developments done within the project under WP3

a. PSP system from SISE

b. Compact DAQ from National Instruments

It is documented the possibility of integration of the algorithms developed during the project in these platforms. In the case of PSP it is limited to a type of algorithm even though after the analysis

done about potential improvements to DACs equipments it is planned in the future to give wider integration possibilities to this equipment.
In the case of using National Instrument, or another generic purpose Data Acquisition System, it is designed a platform able to integrate and test a wider set of algorithms as those developed under WP3.

Using demonstration as a basis, and working closely with the end users involved in the project, served to record process data in real environments that was lately used for the creation of several machine learning algorithms. These analyzed algorithms may be used as a powerful tools for quality control in fabricated plastic parts..

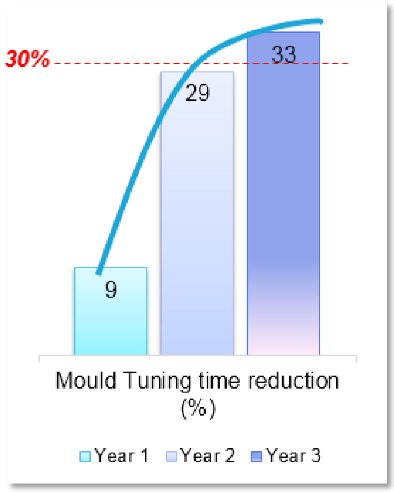
WP5: Demonstration Case Studies

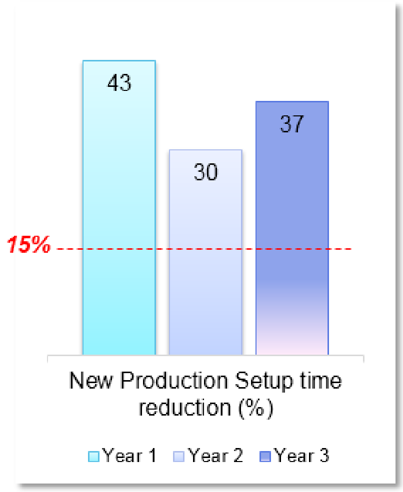
The main results obtained by the three years experimentation are:

- Reduction of Mould Tuning time. The actual reduction has increased from the first run to the third being approximately coincident to the target. In particular the first run of demo mould closed with an average reduction of Mould Tuning time of 9% (target of 1st year: 10%); at the end of the second year of experimentation it was increased to 29% (target of 2nd year: 30%); and at the end of the third year it was 33% (target of 3rd year: >30%).

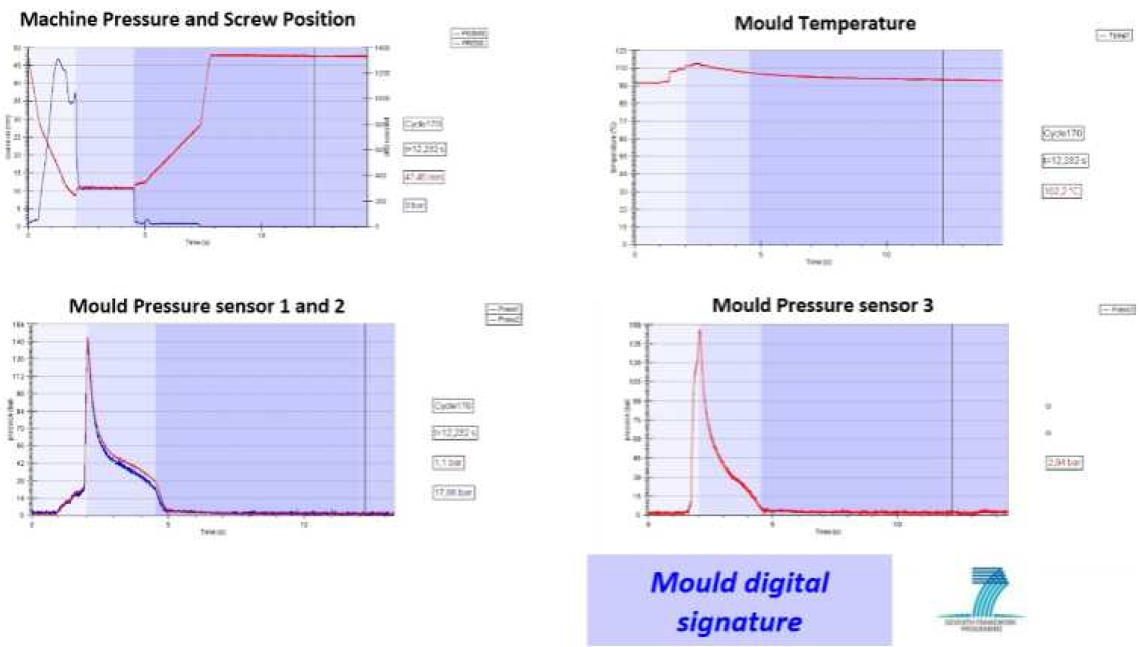
- Reduction of New Production Setup time. After the first year of experimentation the reduction of the time spent for the setup of each new production averaged (over the 4 case studies) 43% (to be compared with the target of the 1st year of 7%); at the end of the second year the Consortium obtained an average reduction of the New Production Setup time of 30% (target of 2nd year: 15%); and at the end of the third year it increased again to 37% (target of 3rd year: >30%). For this assessment key point the actual results have always been highly above the expectations showing thaht the system is very powerful and easy to use in reproducing the Digital Signature that is obtain during the Mould Tuning phase.

- A learning curve could be identified showing that the best results can be obtained with the acquisition of specific skills and competence about moulding with sensors. The trend of n the experimentation over the three years is shown in the following charts:





- Digital Signature.
  It is a set of curves coming both from moulding machine and sensors signals that condensate all the information related to the moulding of 100% in specs parts. An example of digital signature is given in the following picture:



WP6: Dissemination, Training, Exploitation and Technology Transfer

Five electronic training modules were created on the following subjects:

1. Design phase and sensor implementation
2. Practical implementation of sensors
3. DACs for injection moulding
4. Process validation through sensors
5. Process setting with sensors/DACs

Each of the above included a ‘quiz’ in order to test the user’s understanding of the module.

The modules were based on the knowledge developed throughout the course of the project and refined over the series of Regional Workshops and included key information such as demonstration activities like economic advantages together with technical details The purpose of these training modules was to transfer the results of the methodology and logistic developments of the mould makers and end users of the projects.

They have been uploaded onto the project website for future use.

6. Potential impact (including the socio-economic impact and the wider societal implications of the WP so far) and the main exploitation of results (not exceeding 2 pages).

The worldwide market for injection moulded plastics is continuing to grow.

Modern day injection moulding machines are controlled by a built in computer based on sensor fed information. In plastic injection moulding, the primary objective is to manufacture dimensionally and structurally consistent parts, independent of the moulding machine being used. To accomplish this, moulders can benefit from increased process optimization and improved control methods. Turnkey intelligent moulds can offer such an advantage. With the vast sums of money involved; maximising profitability is obviously at the forefront of people’s minds.

Computer modelling and software simulation have become key to meeting these objectives. The first commercial injection moulding simulation software only came to market in 1978. These basic original 2D “layflat” simulations have since moved on to incorporate 3D, shrinkage, warpage, gas-assist, coinjection, multi-shot injection, injection-compression, and thermoset moulding.

Injection moulding simulation software helps manufacturers verify and optimize part and mould designs by providing visual and numerical feedback on injection moulding production. Using optimisation and simulation software helps reduce the need for costly physical prototypes, avoid manufacturing defects and reducing the product’s time to market.

Simulation and optimisation software has become big business in an industry where accuracy and efficiency is king. The global CAE market is expected to post revenue of €2521 million Euro by 2016 (TechNavio 2013). The main players in the market include Mathworks, Ansys, MSC Software, Dassault systems, Siemens PLM, ESI, Autodesk. There is a shift towards global licencing of software which can be used anywhere in the world as vendors push to avoid price differentiation in each region. The major drivers for software market include improved speed to market, reduced analysis time, reduce design cycle, reduced scrap and reduced down time.

Global trends in plastics processing are moving towards lightweight design, increasing functional integration and efficiency of the whole production process. These are posing a significant challenge for injection moulders. Often demands cannot be filled by conventional materials or manufacturing processes. As a result there has been a growth in the market for simulation software which can evaluate different scenarios without incurring the real world costs associated with testing and set up.

With an increasing number of product versions being required by customers the order quantities per product have reduced and the need for a greater number of moulds changes has increased. A direct consequence of this shift in practice has seen the need for reduced turnaround times for tool changes and tool tuning.

While software's such as Autodesks MOLDFLOW, Siemens CADFLOW, Dassualt SIMPOE Mathworks Matlab and MOLDEX among others have focused on anticipating problems in the process, there has been limited investigation into optimisation of moulds into turnkey solutions to enable faster turnarounds for tuning and tool changes. Predicting the physical behaviour of a system based on so many different parameters is a complex task.

Simulation and optimization algorithms which can meet this requirement have the potential to disrupt the market and bring significant cost savings to organisations. This gap in the market should provide strong growth potential along with the possibility of partnering or licencing the software to key players in the marketplace.

The aim of this research was to provide an insight into the injection moulding market and opportunities for software to facilitate turnkey moulds. The study was based on a SWOT and PEST analysis. This approach allowed identification of significant aspects which can affect a positive outcome to the project being achieved.

Key items of note to date include:

The political scenario always has the potential to affect this industry. Increasing concerns about the chemicals in plastics has led to tightening of environmental regulations; there is also a push towards improving end of life modelling of products and improving fire safety. Stricter regulations can have a big effect on the injection moulding industry increasing costs. This may result in reduced costs being allocated for R&D or updating existing facilities affecting the uptake of new systems.

The fact turnkey intelligent moulds are becoming a growing focus suggest the way the injection moulding business operates is changing. Increased product versions are leading to reduced order sizes with flexibility now a significant factor for success. Products which can tap in to this need for flexibility are going to have a high growth rate potential.

Increasing energy costs are becoming the norm and with injection mouldings having such a high energy dependency any products which can help reduce these energy requirements are going to be giving a warm reception within industry.

The key threat will be through open source software with many commercial enterprises now adopting a mixture of both licenced and open source.

The potential for job creation both direct and indirect will be limited as this is more an add-on software solution. Jobs will in general be limited to specialist within the field.

Quality, price, and time to market are critical factors which will determine whether or not the product is successful. The rewards will be relative to the algorithms developed, and its effectiveness.

Protection for the algorithm will need to be a primary focus. It will be important to ensure the name chosen is can be trademarked and consideration will need to be giving as to whether to patent or take the trade secret route.

The prospects which will arise from a successful project outcome are significant. Choosing the correct path to follow to maximise returns on investment will be critical. Consideration should be giving to market exploitation at an early stage to maximise any potential opportunities.

The final results of Mold4ProdE total 5, in different fields, to help the plastic industry increase its competitiveness:

- a Knowledge based system for recommending the selection and location of sensors inside a mould as a WebTool application available on the project website

- a Numerical Optimal Sensor LOcation (OSLO) methodology for polymer injection moulding process

- a User Case Assessment Metrics to evaluate Tuning time reduction, Set up time reduction and the learning curve of operators when embeded sensors are used

- Algorithms for control and monitoring in injection molding process with:

  - a tool to provide “mould signature” and collect related information,
  - a versatile integration platform (from National Instrument) to test different algorithms
  - an optimization of data treatment algorithms
  - Improvements of PSP, the Data Acquisition and Control System from SISE

- Training Modules available on the project website

7. Budget or staff comments.

No any significant changes occurred compared to the initial Description of Work, and there is no major deviation in the budget: in total, 99% of the planned EC contribution and 99% of the planned person-months were used during the whole project.

During the 3 years, the project had to face some issues in the consortium, with SMEs :

- The withdrawal of two initially involved participants, namely Modetec and Progind, created difficulties, but these were efficiently solved by the selection of two new participants, willing to join the consortium.
- The bankruptcy of Nuova Itea slightly delayed the progress of the project, but its tasks were efficiently taken over by the Italian technical center, Proplast, in accordance with the overall timeline.

- Moldelan has been taken over by Goizper and terminated its participation to the project as from 30th September 2011. Since Goizper was also a project participant, this did not affect the tasks and resources involved in the project workplan
- The name of the company Polymeroptix changed into PolyOptix.
- The transfer of rights between participant Poschmann and Nief Plastic has been introduced as an UTRO. Despite the sending of an extensive number of emails, explanations and supporting documents, this process hasn't been finalized yet.