SEVENTH FRAMEWORK PROGRAMME

Nanosciences, Nanotechnologies, Materials
and new Production Technologies – NMP

Contract n° CP-FP 246193-2 TexWIN

TexWIN

Textile Work Intelligence by closed-loop control of product and process quality in the Textile Industry

# Final Report

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# 1 Changelog

| Date | Author | Changes made | Version |
|---|---|---|---|
| 2013-06-06 | Michael Weiss | Progress Report Content | 1 |
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| | | | |

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# 4 Executive Summary


The special focus of TexWIN lies on make-to-order production, small batches and complex high-quality products made of non-homogeneous and/or natural materials. The objectives of TexWIN were to boost productivity by up to 20% and to reduce machinery down-time by one third.

This has been reached by cutting down stop, set-up and waiting times, by increasing process flexibility as well as reliability and by reducing sampling effort. On machinery as well as on plant level,

1. existing knowledge from various factory internal and factory external sources has been identified, captured and reused in order to
2. combine and to evaluate process state information as well as
3. product and material characteristics and to
4. finally derive the best processing instructions and batch-machinery-assignments.

A hierarchical feedback control structure forms the conceptual foundation of TexWIN. It was put into practice by an adaptive and modularised system that complements existing manufacturing execution systems. The system enhances machinery set-up and take-down processes with knowledge management and artificial intelligence (AI) functionality. It integrates and provides an

1. AI-enhanced factory controller for improved process scheduling and event-based coordination of factory (inter-)operations as well as an
2. adaptive case-based machinery controller that suggest the best processing settings regarding both product quality, setting-up and execution efficiency.

A special communication framework enables flexible interfacing with ontology-based information transformation in order to communicate with the company internal software systems like manufacturing execution systems.

The TexWIN approach was introduced and validated in five high-quality textile and plastic mills. The project consortium consisted further of two machinery manufacturers, two enterprise software providers and four research institutes.

# 5 Project Context and Main Objectives

## 5.1 Industrial Situation

Manufacturing of textiles is a complex and distributed process. The products require highest quality for a wide range of variants (e.g. in medical or technical textiles); they often have a very short life-cycle (e.g. in fashion), and are based on natural materials. Production will be done in complex assembling processes (e.g. weaving), in batch processes (dyeing) or in continuous processes. The major production stages are spinning, weaving, knitting and finishing (which includes dyeing).

Fabric production is a one-step process performed at a weaving machine, of which are running up to several hundred simultaneously in a weaving factory. Fabric production orders (e.g. with a length of 500m) are typically make-to-order or make-to engineer-orders, which means, that almost 50% of the orders refer to individual (variants of) articles. Thus 50% of the order requests a timely set-up (e.g. changing weft and warp, changing tools, adjusting machine parameters). Up to 100 machine parameters have to be adjusted, sometimes up to 5 times a week per machine. Typically it is possible to produce one article.

The weaving process is complex. It involves that several thousand warp threads will be combined with sequential inserted weft yarns (with a speed less than 0,2m/min). Yarn breakages, causing machine stops, have to be repaired by an operator. Resulting weaving efficiencies range from 40% for high quality products and low quantity orders more than 95% for mass products.

As the weaving machines are highly flexible production systems, it typically possible to produce one article on many different machine types, with different efficiencies, and settings. But only a few people are able the use the complete potential of the production system (e.g. products for new markets). Despite the huge effort in weaving machine automation, the best machine setting can only be found by trial and error, best after a run-time of more than one week. But today lot sizes are not big enough, so it is almost impossible to produce new articles with sufficient efficiency. TexWIN will close this gap with a new method for determining the best machine setting for a given article with a given yarn material by using CBR for storing and analysing old situations and generating new, adapted machine settings.

Similar situations can be found in all other process stages of the textile industry, in the plastics industry, as well as in many other industry sectors dealing with small batches and workshop production.

## 5.2 Project Context and Main Objectives

The objective of TexWIN was to increase productivity by up to 20% and reduce down-times of machines by one third of workshop factories; due to a reduction of stop times, set-up times and waiting times, increased flexibility and reliability of processes, and due to reduced sampling effort. Enterprises applying TexWIN are able to maximise process quality (capability and efficiency) and product quality (defined product characteristics) and enhance their responsiveness towards unforeseen events in previous production steps and the production of new products.

The breakthrough is to exploit existing knowledge available from various factory internal and factory external sources by (1) combining and evaluating process state information as well as product and material characteristics and (2) deriving best production instructions. Additionally existing production knowledge and experiences from production operators will be preserved and made available by the CBR module.

Therefore a hierarchical control structure TexWIN-Concept consisting of an adaptive and modular system TexWIN-System and re-engineered TexWIN-Processes improving quality of products and processes of workshop factory operations has been developed.

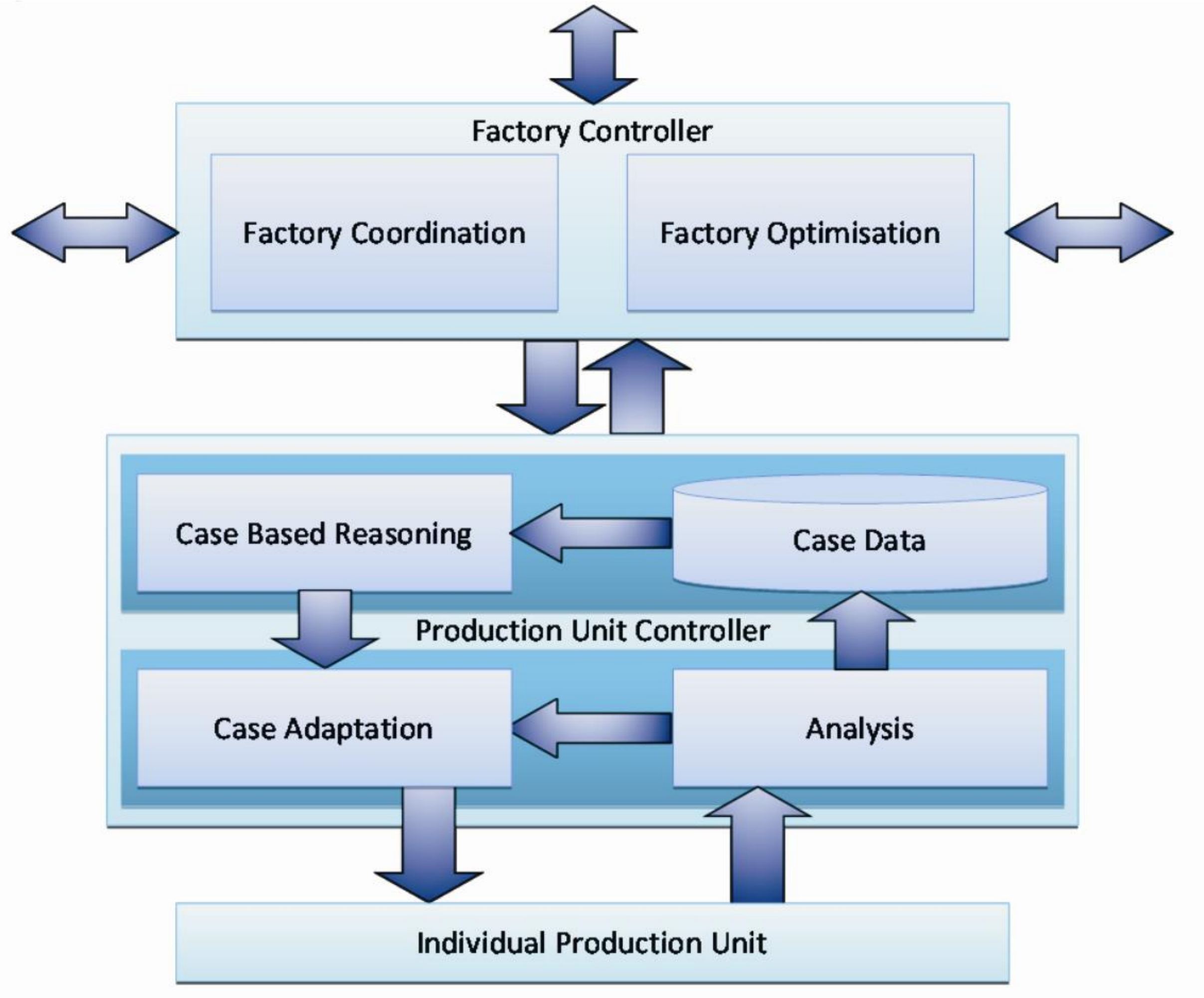



**Figure 1: Hierarchical Control Approach**

The TexWIN-System integrates the two following units: (a) the factory controller for the improvement of the process schedule and event-based coordination of factory (inter-)operations and (b) the adaptive CBR-based production unit controller for identification of best process recipes/machine settings concerning product quality and production process set-up and execution efficiency.

The modules are integrated into a common communication framework, which enables flexible interfacing and ontology-based information transformation. The TexWIN-Processes are adapted factory business processes which allow maximising the efficiency and quality effects and seamless integration into existing factories.

TexWIN is best suited for industries with basically make-to-order production, small batches within workshop production, non-homogeneous and/or natural materials, and large product portfolio with a complex and variable production process, and/or high quality products; in a short for all production processes with production order-individual machine settings or production recipes and a low order repetition rate. The pilot sectors for the project were the textile industry and the plastics industry. TexWIN was tested and demonstrated within 5 industrial environments.

The control structure consists of two layers: the Factory Controller (a) and the Production Unit Controller (b).

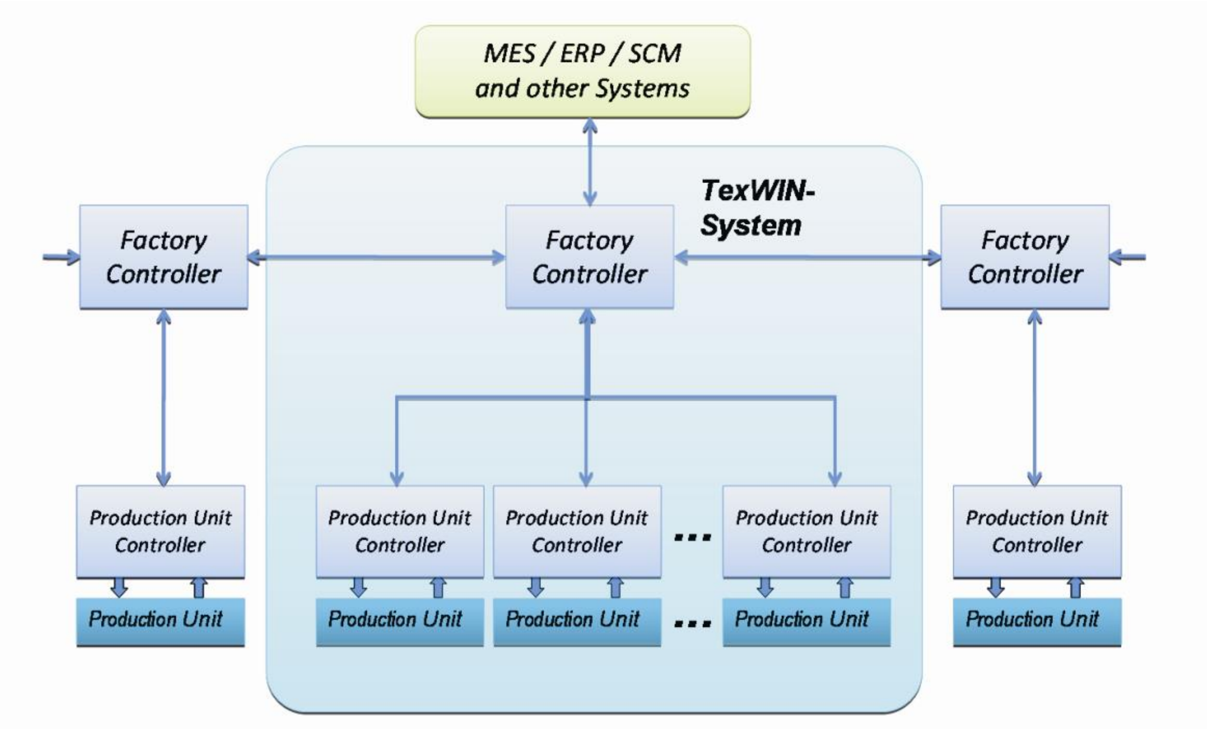



**Figure 2: TexWIN-Concept Control Structure**

The main tasks of the Factory Controller are the optimisation, harmonisation and coordination of the process chain to increase efficiency of the usage of resources like material, energy, etc. To meet these requests the Factory Controller can be applied in two ways. For the first one the Factory Controller uses an information flow which moves in the opposite direction of the material flow in the production process, this means information and specification about quality of the resulting product will be used for optimisation of the production process.

The second way in proceeding the Factory Controller is the ‘coordination’ of a running production process which means that variation of quality of previous process steps will be considered in the planning and execution of downstream processes. Therefore the Factory Controller provides interfaces to communicate with other Factory Controllers, ERP, and MES. Additionally the Factory Controller must be equipped with domain specific knowledge to interpret the received information and transform them for the processing in the following steps. To meet these requirements the Factory Controller consists of two modules, the Factory Coordination and the Factory Optimisation. Both modules use the experience and knowledge collected in the Production Unit Controller to cope with their tasks.

Similar to the Factory Controller the Production Unit Controller consists of two modules. These modules are important for the system to meet the main goal of the Production Unit Controller, which is the experience based adaptive control of individual production units. For the experienced based approach we used the Case Based Reasoning (CBR) method because of the simple integration into the existing processes which helps to lower the inhibition level and the reservation of the Worker. One big problem of CBR is the need of a great number of cases to reach a good solution for individual situation. In the awareness of this problem we developed the case adaptation module to adjust the retrieved cases to the current problem. This functionality enables the usage of the system with a minimum of special cases (e.g. adaptation with genetic algorithm) until a large case base is available.

The creation of a large case base and the adjustment of the adaptation rules are done by the Analysis module. Apart from that functionality the strength of the

Production Unit Controller is the flexibility of the architecture with its ontological knowledge base, which means that the system can be used in different industry sectors by combining the TexWIN Factory Model with a sector specific process and product ontology. The resulting coordination model contains among other things industry-specific case descriptions for the CBR module which is accompanied with the data structure in the case database, some adaptation rules for the case adaptation module, and the configuration data for the analysis module and the process ontology for the Factory Controller.

According to the just given brief introduction the TexWIN-System represents an adaptive multilayer agent-based control system. The property of adaptability was reached with the learning algorithm of the Analysis module to adapt the adaptation rules of the Case Adaptation module and the simple adjustment to new industry sectors by changing the coordination model.

For meeting the label ‘multilayer’ the TexWin-System offers different solutions: On the one hand - based on the system architecture - with an upper layer to perform an optimisation and harmonisation of the process steps and stages; and with a lower layer to perform the production unit specific control mechanism. On the other hand the combination of technical and organisational modifications is a multilayer concept for factory control systems. The TexWIN-System can be regarded as agent-based system in two ways. First the TexWIN-System as a whole can communicate and interact with other Systems e.g. other TexWIN, MES, ERP and SCM systems. Second the System is structured in that way, that the Production Unit Controller of each process step and the Factory Controller itself can be regarded as software agents because of their interaction e.g. for Factory Coordination or Factory Optimisation.

In short the TexWIN project focused on research and development activities leading to the following benefits:

**Determination of initial machine settings in less time**

- Case-Based Reasoning solutions for various textile and plastics production processes
- Integration of information from previous production steps

**Optimisation of machine settings**

- Adaptation of machine settings based on material and process research
- Closed-loop control structures

**Improvement of information flow in factories**

- Integration of information from upstream production steps
- Prediction of product and process quality

**Optimisation of production chains**

- Balancing raw material quality and process performance
- Increasing the flexibility of the production chain by using all available information sources

The results obtained through these activities are best-suited for industries dealing with make-to-order production, small batch sizes, high-quality products, knowledge-intensive processes or natural materials.

# 6 Main S&T results

## 6.1 CBR Case Structures

Cases are represented by objects of a specific object type, which merge the different aspects (information sources) together, e.g.

- specific product (object of object type ‘Products’) that is produced out of
- specific raw material (objects of object type ‘Raw Materials’) on a
- specific machine (object of object type ‘Machines’) with
- specific machine settings (object of object type ‘Machine Settings’).

The specific product could be understood as ‘What’, the specific machine as ‘Where’ and the specific raw material together with the specific machine settings as ‘How’.

The TexWIN Object (Data) Model for Cased Base Reasoning divides between the abstract model on the one hand and the model that deals with concrete instances on the other hand.

The abstract model gives a type description. That means: there is not a concrete, physically existing article, whose construction and raw material elements are described, but the principal construction of articles (products). This model level is the so-called ‘Master Data Level’.

The representation of a concrete, in the real world physically existing article is done on the ‘Production Level’. On this level, an article has got a specific production date, a specific yarn lot, which is the input (or raw) material and a specific machine, on which the article will be or was produced.

### 6.1.1 Master Data Level

The major objects (concepts) to model the theoretical or conceptual world of weaving are:

- the Article (to be produced),
- the raw or input material: Pile Warp Types, Ground Warp Types and Yarn Types (for warps and the weft) and
- the Weaving Machine Types.

Between these objects several references exist as shown in the following figure.

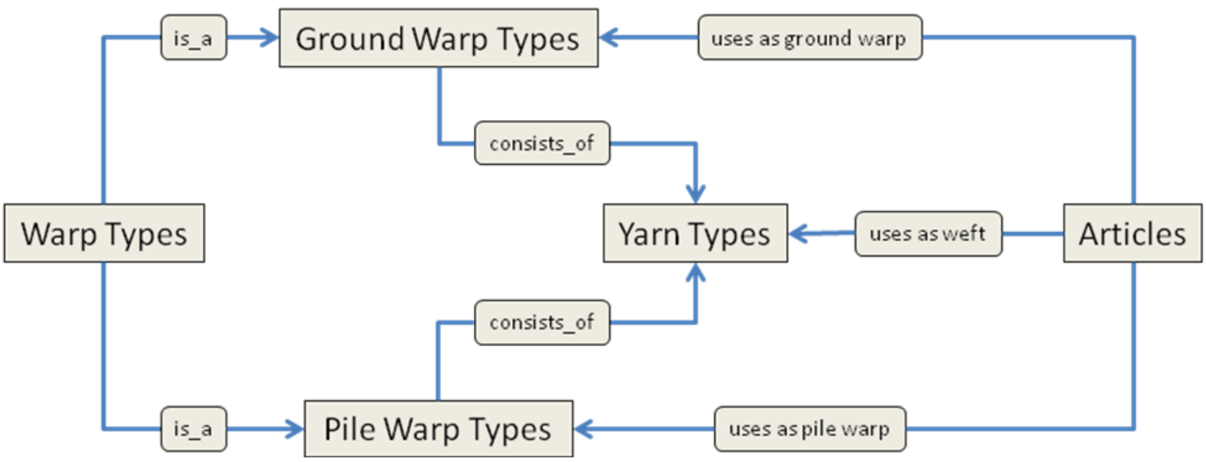



**Figure 3: Master Data Level with major Objects and the Relations between them**

In the following there is a detailed description of these major objects. For each object only those attributes are described in detail, which are relevant for the CBR.

#### *6.1.1.1 Articles (or Article Types)*

Articles respectively Article Types represent the theoretical product, which is produced by the company, here a fabric. Therefore its most important attributes are the following:

- ‘Production Width’: The width of the fabric in cm.

During the finishing processes the fabric shrinks, so that the final product is in both directions (length and width) shorter than the one, which leaves the loom.

- ‘Fabric Length (raw)’ and ‘Fabric Length (finished)’,
- ‘Fabric Width (raw)’ and ‘Fabric Width (finished)’ and
- ‘Weft Density (raw)’ and ‘Weft Density (finished)’: Analogue to the difference between the length of the fabric before and after the finishing, also the weft density changes, but the density increases during the finishing.
- ‘Completed Weight’: In weaving industry (especially for towels with piles) is the completed weight (the weight of the final product in g per square meter [$g/m^2$]) of big importance, because the property is responsible for the ability the absorption of water. The completed weight depends on the pile height.
- ‘Pile Height’: The pile height is partly relevant for completed weight.
- ‘Oeko-Tex Standard 100’: This property keeps the information, whether the article is oeko-tex certified or not.

In addition (the object type) Articles are linked to several object types and uses these references to propagate properties from these object types, e.g.:

- ‘Uses as weft’: This refers to the object type ‘Yarn Types’ and links the Ids of those yarn types (yarn identifiers respectively yarn numbers) to the article, which are used as weft. The Ids of the referenced yarn types are accessible within the object type Article by the attributes ‘Weft Yarn’.
- ‘Uses as ground warp’ and ‘uses as pile warp’: This reference types links Articles to ‘Ground Warp Types’ and ‘Pile Warp Types’. Via these two relation types Articles obtain two additional virtual properties from each target object type:
    - ‘Ground Warp’ and ‘Pile Warp’, which contain the Ids of the related chains.
    - ‘Ground Warp Yarn Types’ and ‘Pile Warp Yarn Types’ that directly access the set of yarn types, the chains are made of.

The relation to the instance view is implemented via the relation type “is produced in” between Articles and the object type ‘Production Order’ (see below).

#### *6.1.1.2 Warp Types*

The object type Warp Types specifies (beyond others) the most relevant attribute for warp: ‘Yarn Types’, of which the warp is consists.

From this object type two types are derived, which represent the concrete warp types:

- ‘Pile Warp Types’ and
- ‘Ground Warp Types.

#### 6.1.1.3 Weaving Machine Types

This object type is derived from the more common “Machine Types”, to which the “Knitter Types” belong, too.

There is only a few CBR relevant attribute for Weaving Machine Types:

- ‘Width’: Stores the maximum width (in cm) of machines of this type. This limits the size of fabrics, which can be produced on such a kind of machine.
- ‘Number of Weft Colours’: Similar to ‘Width’ this attribute stores a limitation of machines of this type. In this case, it is the maximum number of different colours, the machine can use for the weft.
- ‘Speed’: This is the typical (or standard) number of beats per minute. It is not a limit, but a producer defined default setting.

### 6.1.2 Production Level

As already mentioned previously all objects on Production Level represent a concrete, physically existing object of the real world, e.g. an article that is a piece of produced fabric.

The most relevant objects on this level are the one shown below.

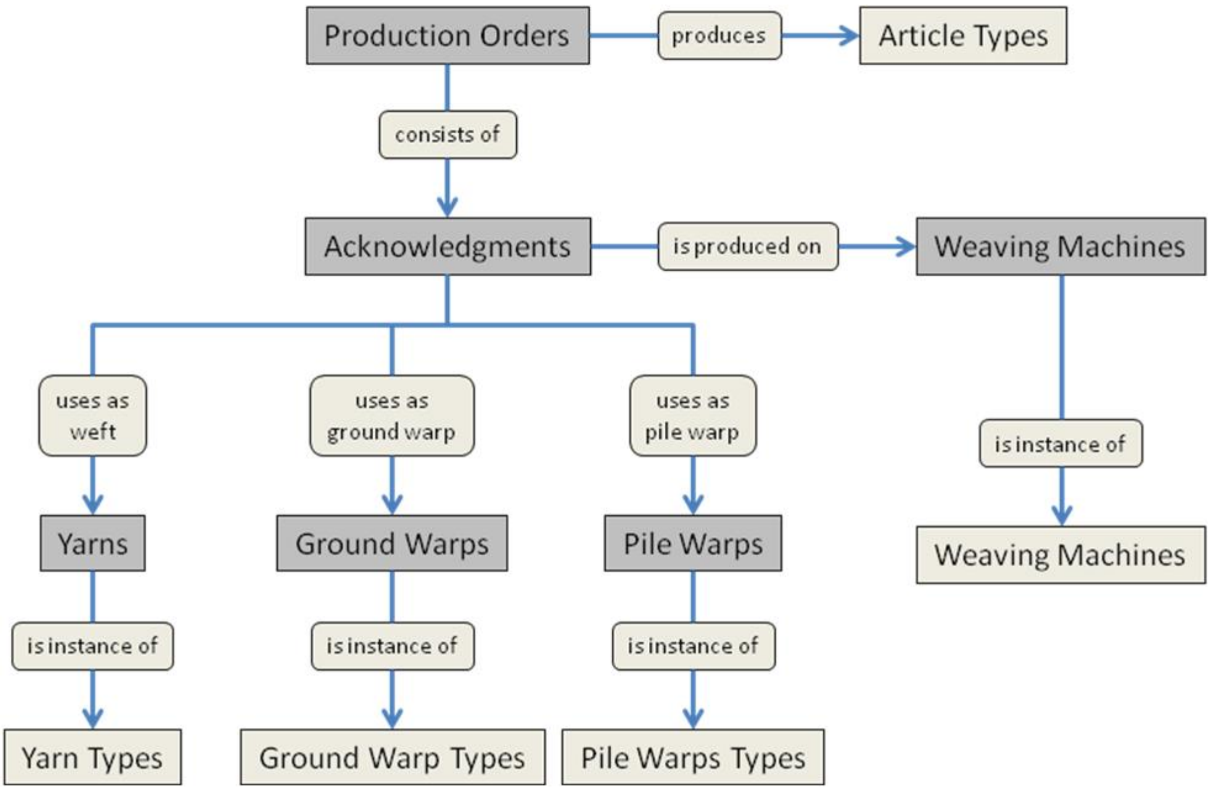



**Figure 4: Major Objects on Production Level (dark grey) and the Relations to Master Data Level**

The kernel object for the Cased Base Reasoning is the ‘Acknowledgment’. It merges those objects that deliver the CBR relevant information, as:

- What was produced?

- Where was it produced (which machine was used)?
- What were the input materials?
- What machine settings were used?
- What are the efficiency (process properties or monitoring values) and quality (product properties) values?

In fact there is not a big difference between ‘machine settings’, ‘monitoring values’ and ‘product properties’. All three can be seen as operating figures of the production process.

In the following there is a more detailed description of the major object (types) on Production Level and their attributes and relations.

#### 6.1.2.1 Production Orders

This object type builds the link between the Article (Type), which was produced (past tense due to the fact, that a production order is only relevant for CBR, if it’s acknowledgments exists, that means after the production process) and the smallest unit within the production process, the Acknowledgements. The division between a ‘Production Order’ and ‘Acknowledgments’ is needed, because often machine settings are modified during the production process, which leads to a new case for the CBR.

#### 6.1.2.2 Acknowledgments

An Acknowledgement is defined as the smallest unit (block, period) within the production process, which means, between the beginning and the end of this period, there were no changes at all: neither a change on the machine settings nor on the input material lot. Typically there is one Acknowledgement each specific number of meters, e.g. each 50 meters. If there has been made no modification since the previous Acknowledgement, then these two (or even more) Acknowledgments can be combined to one Acknowledgment and so to one case of the CBR.

The attributes of an Acknowledgment, which are most relevant for CBR, can be divided in the following three areas:

- Product properties like completed weight, fabric length and width or pile height.
- (Process) Monitoring values like number of warp breaks, number of weft breaks, number of stops or efficiency.
- Machine settings like reed arrester distance, number of sheds’, shed 1 open angle or shed 2 open angle.

Because an Acknowledgement builds more or less one case, it is necessary to propagate a number of additional attribute values via relations from other objects. The following figure shows a screenshot of the DITF Retrieval System with an Acknowledge object (in Edit mode).

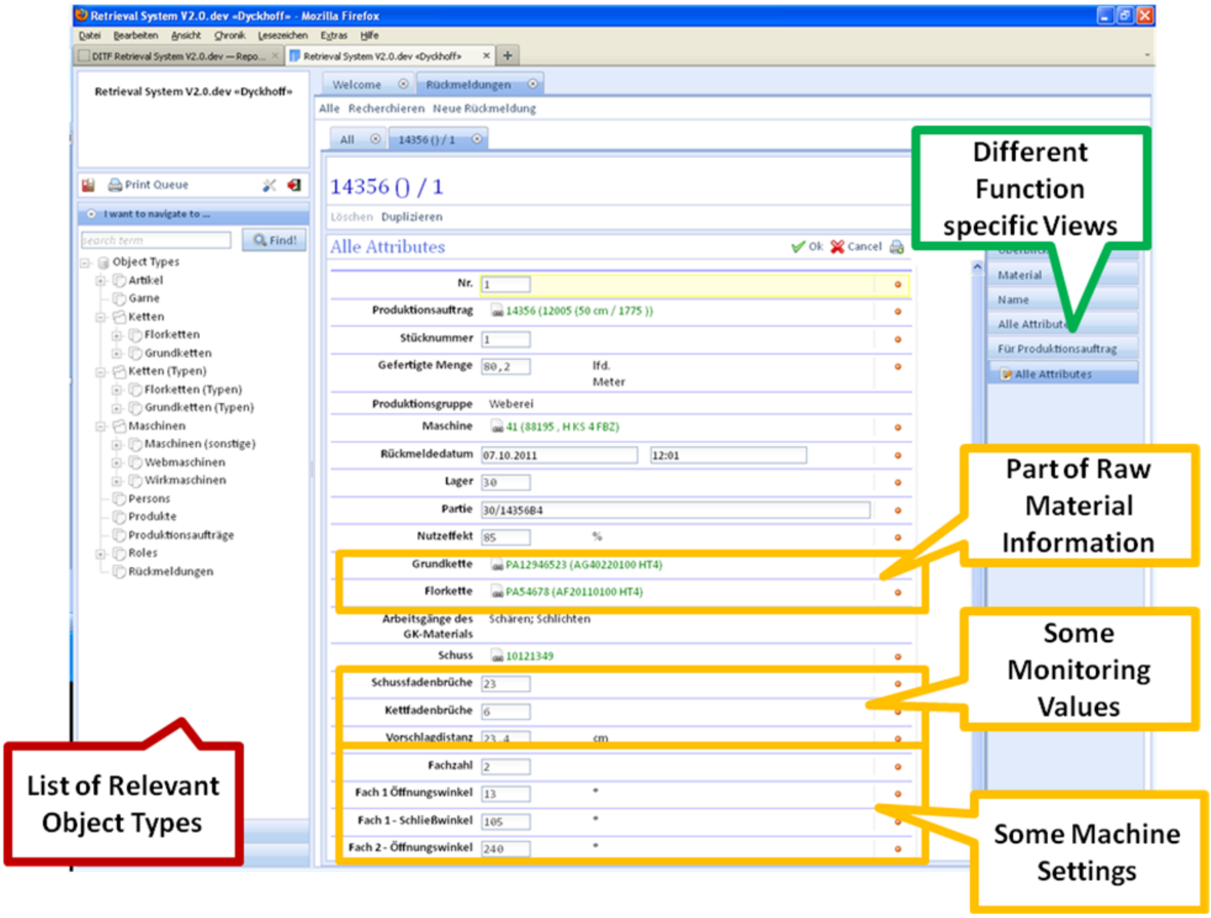



**Figure 5: Screenshot of an Acknowledgement object**

Product properties, (process) monitoring values and machine settings saved in Acknowledgments are relevant for finding best machine setting for a given article specification.

### *6.1.2.3 Yarns*

Yarns are physically existing instances of Yarn Types, often called Yarn Lots. The quality of the Yarn decides, whether it is usable for one of the warps or only for weft. The requirements to the quality of a yarn, which should be used as warp yarn, are higher than the ones for weft yarn, especially concerning the tensile strength. Yarns propagate their information via the relation ‘uses as weft’ to Acknowledgements.

### *6.1.2.4 Ground Warps and Pile Warps*

Concerning the Data Structure there is no difference between the object types ‘Ground Warps’ and ‘Pile Warps’. The only cause to specify two different object types is to ensure, that always the correct kind of warp object has to be related to Acknowledgments. This is made sure when using the relation type ‘uses as ground warp’ and ‘uses as pile warp’, via those the relevant attribute values are propagated to Acknowledgments. The information about Yarns, Ground Warps and Pile Warps is needed for identification of articles with specific preliminary products.

### *6.1.2.5 Weaving Machines*

Due to the fact, that all machine settings are saved directly in the Acknowledgments, there is no CBR relevant attribute defined for Weaving Machines. In this case only the Id off the Weaving Machine respectively the existence of the relation using the relation type ‘is produced on’ between Acknowledgments and Weaving Machines is necessary.

## *6.2 CBR Similarity Functions*

The similarity functions, in general, are very important for several algorithms in CBR systems. Most CBR algorithms use a similarity measure to assess its results. To understand the concept of "Similarity", the different definitions follow:

> *"Similarity is some degree of symmetry in both analogy and resemblance between two or more concepts or objects. The notion of similarity rests either on exact or approximate repetitions of patterns in the compared items"* by Wikipedia
>
> *"Similar: of the same kind in appearance, character, or quantity, without being identical"* by Oxford dictionary
>
> *"Similar: having characteristics in common: strictly comparable"* by Merriam-Webster dictionary
>
> *"Distance: the degree or amount of separation between two points, lines, surfaces, or objects"* by Merriam-Webster dictionary

So, a similarity metric is merely a function that gives a generalized scalar distance between two arguments - patterns, vectors or instances.

The objects that are used in TexWIN are vector of attribute-value pairs, where each vector has the same definition for each position (attribute).

So, the vectors could be seen as points in a space where the coordinates are the attributes. The coordinates are not necessary orthogonal, depending on the correlation among the attributes.

Calculating the similarity or distances between two cases depends on the chosen distance (in the next subsection we define the distances that are going to be tested) and, also, on the weights defined for each attribute. The similarity measures are an essential part of the retrieval step of CBR cycle to decide which would be the optimal case to be selected to solve a new problem.

A retrieval method should try to maximise the similarity between the actual case and the retrieved one(s). And this task usually implies the use of general domain knowledge. Selecting the best similar case(s), it is usually performed in most case-based reasoning systems by means of some evaluation heuristic functions or distances, possibly domain dependent. Commonly, each attribute or dimension of a case has a determined importance value (weight), which is incorporated in the evaluation function. This weight could be static or dynamic depending on the CBR system purposes. Also, the evaluation function computes an absolute match score (a numeric value), although a relative match score between the set of retrieved cases and the new case can also be computed.

Cases are commonly represented as a vector of attribute-value pairs. Thus, similarity measures used fall within the second kind of the above mentioned approaches. In such a situation, these systems can use a generalised weighted dissimilarity or distance function, which can be generally described as:

$$dist(x,y) = \frac{\sum_{k=1}^{K} w_k * atr_{dist}(x_k, y_k)}{\sum_{k=1}^{K} w_k},$$

*where k is the number of attributes, x and y are whatever pair of cases, $x_k$ is the value of the instance x for the attribute k, and $w_k$ is the weight or importance of the attribute k.*

In the literature there are different similarity measures and these have a performance strongly related to the type of attributes representing the cases and to the relevance of each attribute. Thus, is very different to deal with only continuous data, with ordered categorical data or non-ordered categorical data. To give a greater distance contribution to an attribute than others less important attributes is necessary to define the weights (relevance) of the attributes.

The TexWIN case structure is composed by a list of attribute-value pair. What have the distance measure to satisfy?

- Knowledge domain is unsupervised, there are not a class indicating if the case belongs to a one class or another.
- Heterogeneous. The nature of the data is different. The attributes can be numerical, non-ordered categorical and categorical or other structure type
- The distance measure has to deal with weights and also, return good results if the weights are the same.
- The data should be normalized or standardized in order to compare the differences of the different attributes.

It is suggested the heterogeneous version of the Euclidean Distance that belongs to the Minkowski family or L'Eixample because almost all the attributes are numeric. In the case that the weights are not present in some cases, it is suggested the Clark or Canberra measures.

### 6.2.1 Distance between two Cases

The similarity of two cases is computed using a distance metric. Thus, given two cases $C_1$ and $C_2$, the similarity function is

similarity($C_1$, $C_2$) = 1 – distance($C_1$, $C_2$), if distance is between [0,1]

distance($C_1$, $C_2$) = function(distance(attributes))

Distance(attributes) depends on the kind of attribute. In this case, the following types of attributes are identified:

- Material
- Numerical attributes
    - Attribute that grows linearly
    - Attribute that does not grow linearly. In instance "Count"

The distance metric that assesses all the attributes together, is a function that can contain weights if those are defined. As approach, we use a modification of the Minkowsky distance in order to handle heterogeneous data (different types):

Extended Minkowsky metric (Manhattan R=1 and Euclidean R= 2)

$$\text{Distance}(x,y) = \sqrt[R]{\frac{\sum_{k=1}^{K} w_k * \text{distance}_k(x_k, y_k)^R}{\sum_{k=1}^{K} w_k}},$$

*where $distance_k(x_k, y_k)$ is the distance between two values of attribute k.*

### 6.2.2 Distance Count

Count (Nm): number of yarn meters per each kg (the lower the number the thicker the yarn).

According to the textile experts' opinion the distance between two values near the origin is bigger than those far from the origin. For instance comparing values as 3 and 5 are more different than 51 and 53. In such case we assume that the distance has not a linear growing.

Therefore, we look for metric that catch this effect. Given $c_1$ and $c_2$, two values of count that has maximum value $c_{max}$ and minimum value $c_{min}$ then we propose the following measures:

- Logarithmic
- Canberra
- Relative

In next graphs the distance behaviour is visualized. Each graph shows the three calculated metrics that are proposed and the absolute metric. The first graph shows the distance when comparing count=1 (Nm) to counts in [1, 51](Nm). The second graph shows the same distance metrics when comparing count= 14(Nm) to counts in [1, 51](Nm)

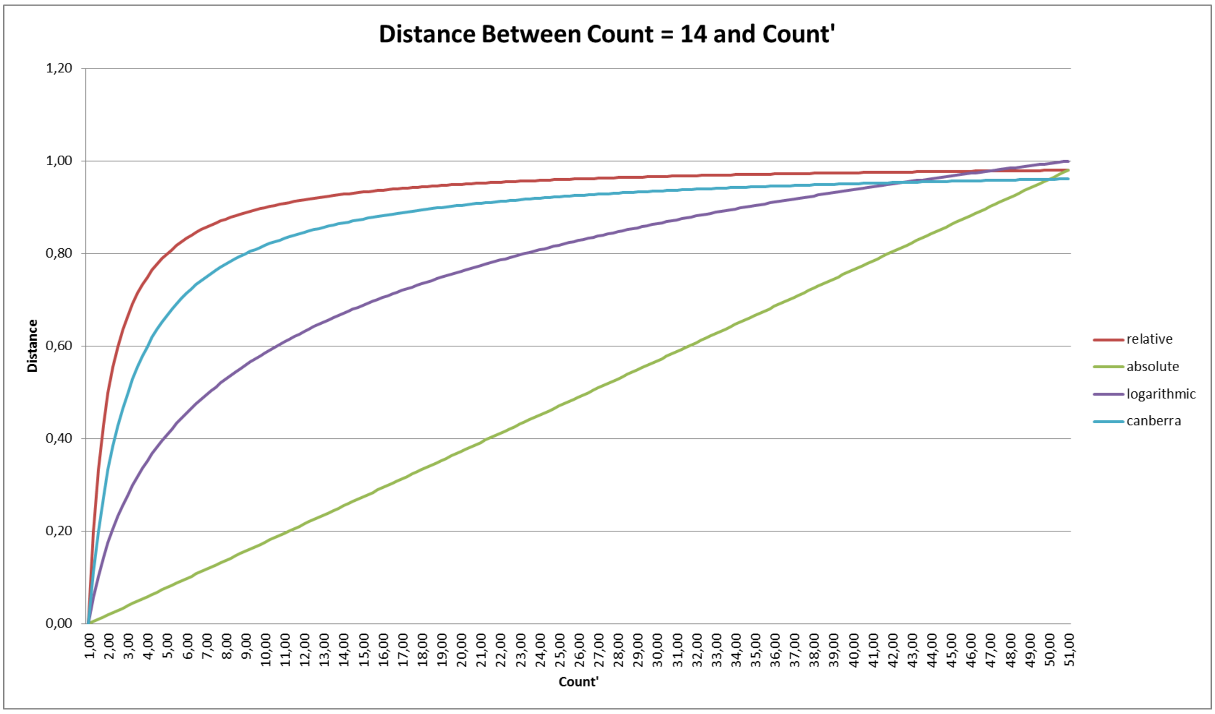



**Figure 6: Distance count=1 to counts in [1, 51]**

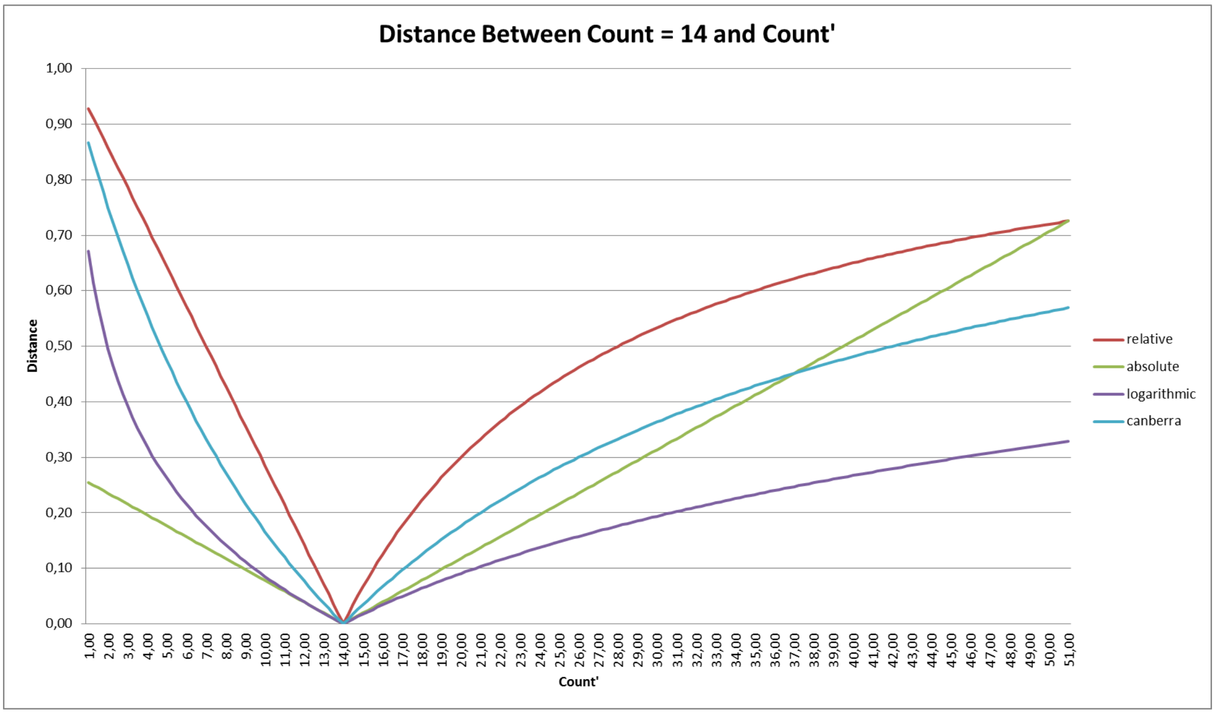



**Figure 7: Distance count=14 and count in [1,51]**

### 6.2.3 Distance between two Yarn Types

In this section is explained how a yarn is modelled. A yarn is a composition of components (a component is a yarn or a fibre) and each component has a percentage of presence. Hence, the distance is decomposed in two parts:

- How the different components of the yarn can be compared
- How different are two components

A yarn is a composition of n components. A component is another yarn or a fibre. One of the components is the main one (higher presence in the material – higher percentage)

Then a material is:

- Yarn Code (identifier)
- List of pairs: percentage (%), component code

Component contains:

- Material family type
- Component code
- Fiber length
- Fiber fineness

For the material family types, there is a table (*Material Table*) (see following table) that says how badly is to substitute one material by another one (in each cell there is a distance between two material types, from 0 to 1).

**Table 1: Material Table**

| | WO | | COR | | CO | | PC | | AR | | LI | | PA | | PP | | PL | | SE | | VI | | XX | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WO** | 0 | 10 | 3 | 7 | 3 | 7 | 7 | 3 | 9 | 1 | 2 | 8 | 4 | 6 | 4 | 6 | 5 | 5 | 3 | 7 | 8 | 2 | 10 | 0 |
| | 1 | 1 | 1 | 1 | 5 | 7 | 14 | 22 | 1 | 1 | 1 | 1 | 11 | 16 | 1 | 1 | 13 | 15 | 1 | 1 | 12 | 14 | 1 | 1 |
| | 1 | 1 | 1 | 1 | 6 | 6 | 1 | 2 | 1 | 1 | 1 | 1 | 1,1 | 1,6 | 1 | 1 | 1,1 | 1,3 | 1 | 1 | 0,9 | 1,1 | 1 | 1 |
| **COR** | | | 0 | 10 | 0 | 10 | 1 | 9 | 9 | 1 | 2 | 8 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 3 | 7 | 10 | 0 |
| | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **CO** | | | | | 0 | 10 | 7 | 3 | 9 | 1 | 3 | 7 | 9 | 1 | 9 | 1 | | 1 | 5 | 5 | 2 | 8 | 10 | 0 |
| | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PC** | | | | | | | 0 | 10 | 0 | 10 | 6 | 4 | 3 | 7 | 4 | 6 | 2 | 8 | 5 | 5 | 1 | 9 | 10 | 0 |
| | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0,5 | 0,7 | 1 | 1 | 2,2 | 2,2 | 1 | 1 | 0,6 | 1 | 1 | 1 |
| | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0,8 | 1 | 1 | 1 | 1,6 | 1,6 | 1 | 1 | 0,9 | 1 | 1 | 1 |
| **AR** | | | | | | | | | 0 | 10 | 6 | 4 | 4 | 6 | 5 | 5 | 2 | 8 | 5 | 5 | 1 | 9 | 10 | 0 |
| | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1,3 | 1,3 | 1 | 1 |
| | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **LI** | | | | | | | | | | | 0 | 10 | 9 | 1 | 9 | 1 | 9 | 1 | 7 | 3 | 9 | 1 | 10 | 0 |
| | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1,1 | 1,1 | 0,8 | 0,8 | 1,1 | 1,1 | 1 | 1 |
| **PA** | | | | | | | | | | | | | 0 | 10 | 2 | 8 | 4 | 6 | 5 | 5 | 8 | 2 | 10 | 0 |
| | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1,1 | 1,9 | 1 | 1 |
| | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0,8 | 0,8 | 1 | 1,1 | 1 | 1 |
| **PP** | | | | | | | | | | | | | | | 0 | 10 | 7 | 3 | 8 | 2 | 9 | 1 | 10 | 0 |
| | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **PL** | | | | | | | | | | | | | | | | | 0 | 10 | 3 | 7 | 4 | 6 | 10 | 0 |
| | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **SE** | | | | | | | | | | | | | | | | | | | 0 | 10 | 4 | 6 | 10 | 0 |
| | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | | | | | | | | | | | 1 | 1 | 1,1 | 1,3 | 1 | 1 |
| **VI** | | | | | | | | | | | | | | | | | | | | | 0 | 10 | 10 | 0 |
| | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 |
| | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 |
| **XX** | | | | | | | | | | | | | | | | | | | | | | | 0 | 10 |
| | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 |
| | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 |

| Ex | PC | |
|---|---|---|
| | 3 | 7 |
| WO | 5 | 7 |
| | 4 | 6 |

Distance = 3

Optimal Ratio dtex(WO)/dtex(PC) between 5 and 7

Optimal Ratio nm(WO)/nm(PC) between 4 and 6

As it was mentioned, the yarn material is a composition of components. In addition, there is a set of families that has different properties and cannot be replaced by any material. These materials are defined as critical materials. The behaviour of a critical material depends on the proportion of this material in the yarn. For this reason, if a yarn contains one of the critical material and its percentage is higher than a given threshold then this critical material cannot be replaced by other material, otherwise could be.

Then, so as to compare yarns, a pre-filter is defined. This filter restricts the possible yarns to be compared depending on the proportion of critical materials. The algorithm of this filter is the following:

```
If (yarn contains critical materials > threshold)
compare with yarns that contains this critical material in similar
proportions
else
compare all yarns
```

For comparing the different yarns we propose 4 algorithms. Then, the resulting distance as a first approach is the average of those four algorithms.

These four algorithms are strategies in order to compare the components of the yarns taking into account the percentage of presence. Also, two of them are taking into account that one of the components is the main component. The proposed algorithms are the following:

- MainMinAlgorithm: Takes into account the main material. Then, following a greedy strategy that finds combinations of components which are more similar, computes the distance of all the found combinations.
- MinAlgorithm: The same as previous but does not take into account the main component.
- CrossAlgorithm: Combines all components that are different and gives a rank average of the difference depending on the percentage of each component
- MainHigherAlgorithm: Takes into account the main component. Then, compute the distance of the rest of components, selecting pairs of components with higher percentage.

Therefore, the distance between two yarns is the following:

*Distance(yarn1, yarn2) = mean(MainMinAlgorithm, MinAlgorithm, CrossAlgorith, MainHigherAlgorithm)*

All of these algorithms use the distance of two components which is based on the material type, fibre length and fibre fineness.

## 6.3 CBR Case Adaptation

In the textile domain similarity and retrieval tasks are of high complexity. In addition, the degree of difficulty of the adaptation step is not so high, because it is more important to get the “correct” most similar cases, than proposing a very sophisticated adaptation method. For this reason, the most used adaptation techniques in the TexWIN prototype system are common strategies like the copy solution technique or some numerical adaptation strategies which will be detailed in the following. Nevertheless, some specific adaptation strategies have been designed specifically for some end user cases, as it will be described later.

The adaptation must take into account some issues:

- Criteria selecting the case/s from the retrieved cases
- Recognize when an adaptation should be applied
- Each attribute can require different adaptation methods

Another feature to be taken into account is the possible interdependency of the attributes among themselves. This interdependence imposes a certain order in the computation procedures to get the estimated values for the solution attributes. Below a concrete example is presented to clarify this problem.

### 6.3.1 Interdependency of Solution Attributes

The user introduce for a new product the following input attributes:

- Sector
- Count
- Composition of the material

The output of the retrieval should be a list of machine settings. For instance, let us suppose that the settings for a machine are the following:

- COUNT Nm

- PRODUCTION
- GREAT CYLINDER SPEED
- FLAT SPEED
- SHODDY RECYCLE
- DRAFT IN EXIT
- SPEED IN EXIT
- DRAFT
- METERS EACH CAN

The premises for the CBR strategy are the following:

- Some parameters can be inferred by cases from different sectors, but not all.
- Each output attribute could be inferred from different cases

Since each attribute could be inferred from different cases, the query can be broken down (split) for each output attribute. In addition, each attribute needs different case base or different weight settings and also, there is some dependence between settings.

We propose to calculate the attribute which can be assessed by a specific formula (e.g. torsion) and then, computing a CBR with each output attribute depending on the dependence of these attribute. In instance, “rotor speed” and “moire” depend on “rotor type”.

At this point, a new issue arises and it is the order of the executions. One way to solve is to create a dependency graph of all the attributes. With this graph, each time the CBR is called you have more values to put in the case description. Finally, ones all the dependences are solved, then rest of the output attributes as a solution are computed together by other CBR.

In the following pseudocode there is the schema to follow:

```
While (there are output attributes)
Output = take Output Attribute with satisfied dependencies
CBR(input attributes, output , weights, knowledge about output)
Put Output in Input Attributes
endWhile
```

In a table the dependencies of each attribute to the input or other output attributes is fixed. In this table the dependency are assessed by percentage (%) and in that case, two attribute depend on the “rotor type” that it is not input attribute. Therefore, first the “rotor type” has to be solved.

Then,

```
CBR( input, output={rotor type}, …)
CBR(input + {rotor type}, output={…}, …)
…
```

### 6.3.2 Common Adaptation Strategies

Common adaptation strategies can be applied to most CBR systems, as they do not require great efforts in the computation part of the solution values. Below there is the principal strategies that could be used in the TexWIN system. In fact, several of them have been incorporated to the TexWIN prototype systems like the copy strategy, some numerical adaptation methods, and some preliminary work on some hybrid adaptation methods (rule-based adaptation scheme).

- *Null or Copy*: The small differences are abstracted away and they are considered as non-relevant. This adaptation strategy is somewhat trivial but widely used because it is domain independent. The proposed value for one attribute is the same value of the corresponding attribute of the most similar case. Of course, this strategy is reasonable when the degree of similarity between both cases is very high.
- *Transformational Adaptation*: The past case solution is not directly a solution for the new case, but some knowledge domain exists in the form of transformational operators:
    - Numerical Adaptation methods: these methods propose an estimation of one attribute solution value by means of some mathematical computation.
    - Hybrid Adaptation methods: these methods usually use some machine learning model or reasoning paradigm integrated in the adaptation step of the general CBR cycle. In the literature there are different hybrid CBR systems applied in different specific domains.

### 6.3.3 Numerical Adaptation Methods

These methods propose the estimation of one solution attribute value through the computation of some mathematical function or procedure. There can be divided in generic numerical methods and specific numerical methods. Generic methods use common mathematical functions which, in principle, can be used for whatever attribute. Specific methods use a particular mathematical function specially designed for a particular attribute.

### 6.3.4 Generic methods

- Mean/Mode: the mean/mode of the corresponding attribute among the selected retrieved cases is proposed as the solution value for the attribute in the new case.
- Weighted Mean/Mode: for quantitative attributes, the weighted mean of the corresponding attribute values among the selected retrieved cases is computed and proposed as the solution value for the attribute in the new case. For qualitative values, an average of the weighting scheme (distance, utility, quality, etc.) is computed among the retrieved cases with the same qualitative label. Finally the “best” qualitative label according to the weighting scheme is proposed as the solution value for the attribute in the new case. The cases could be weighted according several dimensions (Distance to the new case, Utility of the case in the case base, Quality of the solution case, if available)

### 6.3.5 Specific methods

- Formulas: the use of a customized formula for one attribute is a good choice whenever some expert knowledge is available to provide the formula for the computation of the new value for the solution attribute value. For example, in Marchi & Fildi, the industrial partner has provided a formula to calculate the Twist. The formula has been incorporated to the TexWIN prototype and used for proposing a new value for the Twist attribute.

### 6.3.6 Hybrid Adaptation Methods

These adaptation methods commonly use some machine learning model or reasoning paradigm integrated in the adaptation step of the general CBR cycle. In the literature there are different hybrid CBR systems applied in different specific domains. These methods normally share some common characteristics like the following ones:

- They assume that the Case Base is representative enough of the domain:
    - Case Base is a good representative sample of the target
    - The problem space does not change over time (not incremental)
- The description part and solution part are fixed. Therefore, the attributes belonging to the case are always the same.
- The solution part is formed of a unique attribute, and commonly it is a categorical attribute.

Most common hybrid methods used in the CBR research field are:

#### *6.3.6.1 Rule-based Adaptation*

This kind of techniques is based on the use of background knowledge, normally provided by experts in the domain, which are coded into if-then rules. Thus, normally rules must be incorporated in the CBR system by the experts.

Also, rules could be learnt from the case base, as for instance, rules could be generated from the differences between pairs of cases. That means that the rules are generated with all the cases.

On the other hand, there are some constraints on the application of these techniques:

- They are only oriented to categorical attributes. Quantitative attributes must be discretised.
- They are useful for only one solution attribute. For more than one solution attribute, more sophisticated methods should be designed.

#### *6.3.6.2 Artificial Neural Networks*

The basic idea is to use ANN for the prediction of the value of one solution attribute. The *m* retrieved cases in the similarity step are used to build and train the artificial neural network.

On the other hand, there are some constraints on the application of these techniques:

- Specifically oriented for numerical attributes
- They are useful for only one solution attribute. If there are several solution attributes, a different ANN for each attribute should be configured, calibrated, and used.
- The complex configuration of the ANNs involved in the adaptation scheme
- A lot of data (cases) are needed to calibrate these models

#### *6.3.6.3 Genetic Algorithms*

The strategy is to use the m retrieved cases in the similarity step as the initial population of a genetic algorithm. This genetic algorithm must evolve their individuals (the similar cases) until the “optimal” individual is found. This “optimal” individual must be the most similar case to the new problem (case) that the system is trying to solve. The fitness function for each individual could be evaluated through the similarity between the new case and the corresponding individual. Thus the optimal individual will be the most similar one that can be “evolved or generated” from the population of most similar cases.

On the other hand, there are some constraints on the application of these techniques:

- The *m* retrieved cases must be representative (really similar to the new case)
- Usually individuals must be transformed into binary data
- The definition of the fitness function should be provided
- A lot of data (cases) are needed to calibrate these models

### 6.3.7 Colour Adaptation

The problem is to compute the concentration correction factor between two basic colour deliveries. This is done by comparing the two corresponding sets of loading curves (see next two diagrams).

On the first diagram two sets of loading curves are represented while using the same concentration scales (left and right ordinate axes). This allows us to observe the differences between the two. On the second diagram, we have adjusted the scale of the second set (red) in order to fit the first one as best as possible.

This representation aims to show the visual quality of the bond. The objective is to illustrate in a single diagram the remaining differences (i.e. after implementation of adaptation) between absorbance spectra for the whole range of practically used concentrations.

It should be noted that the cyan has two peaks and is more difficult to work with. The orange and the purple for example offer apparently better results. Nonetheless, if we look at the cyan closer, the two families of curves are well adjusted in the range where the eye is most sensitive.

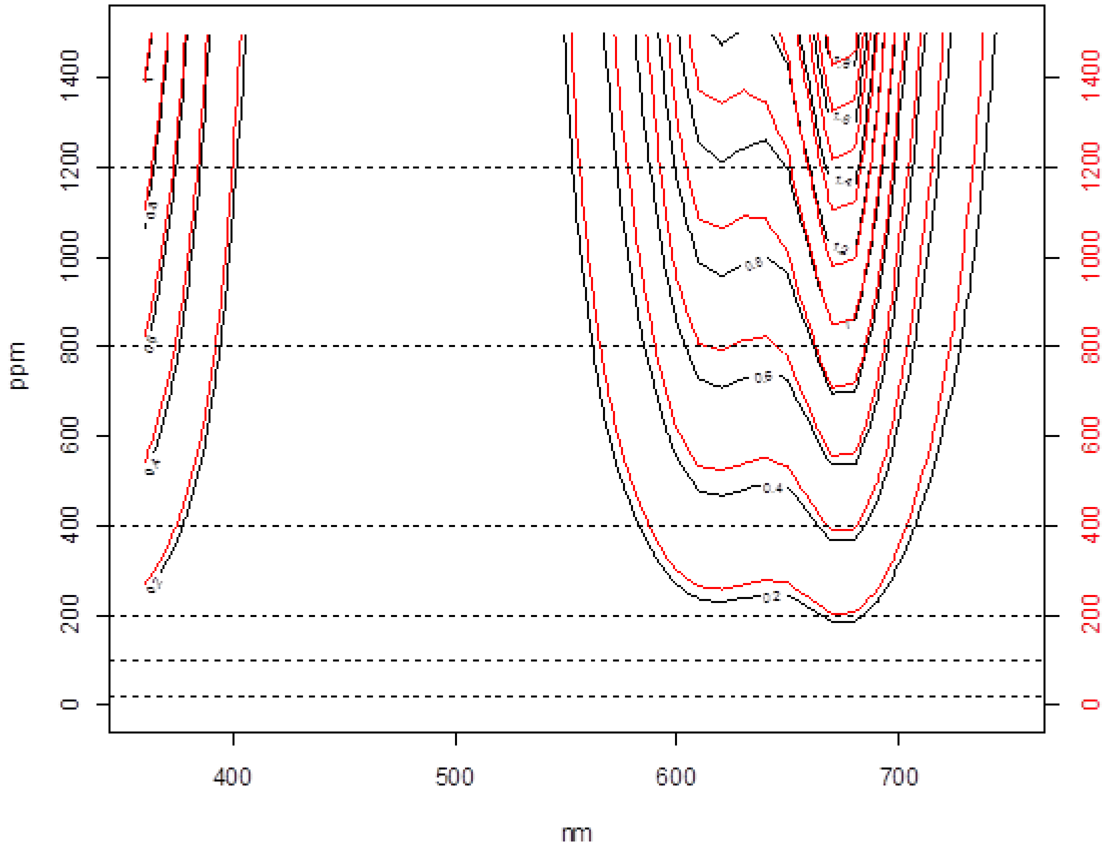



**Figure 8: Estimated absorbances of batch “cyan 1” (black) and batch “cyan 2” (red)**

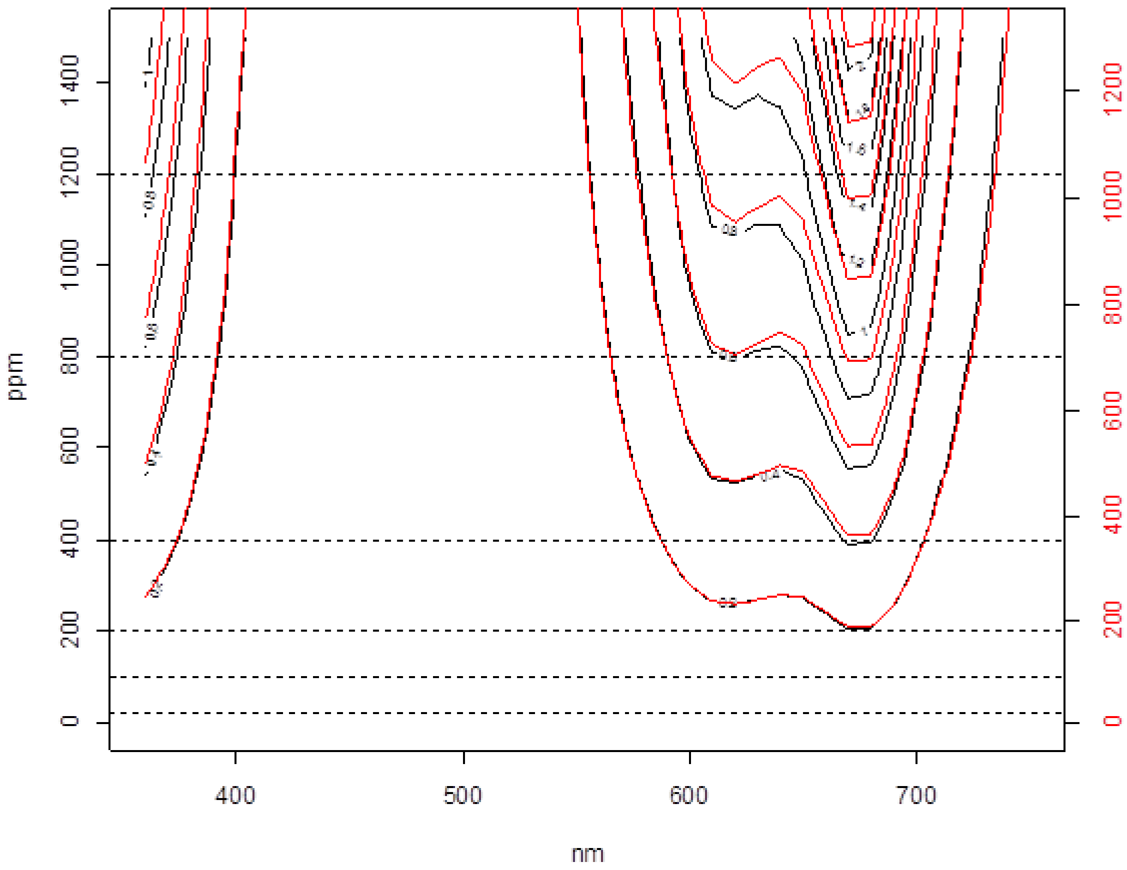



**Figure 9: “cyan 2” scale adapted to match optimally with “cyan 1”**

#### 6.3.7.1 *Colour adaptation steps*

First, we adjust a model for batch B absorbance versus concentration c separately for each wavelength: $\lambda \to A_B(c;\lambda)$

Then we define a measure of colour difference between spectra $A_B(c;\lambda)$ and $A_{B'}(c';\lambda)$ for any fixed pair value $(c, c')$

Finally, we minimise the colour difference by adjusting : $k_{B\to B'}(c) = c' / c$

The colour difference is an average quadratic relative difference of transmittances that is weighted by F2 illuminant intensities multiplied by luminance (variation of perceived brightness with wavelength).

For the adjustment we use an algorithm, which gradually change the concentration until it reaches a minimum between the absorbance spectra of the two compared batches. This value becomes the final value of adaptation.

This exercise is repeated for a series of concentrations and allows us to compute the factor for each of them. As already explained, this factor is not constant but it evolves almost linearly and with a slope relatively low inside the range of concentrations were are interested in (0-1200 ppm). The simplest form for the k factor dependency on concentration is a linear function using two coefficients (offset and slope).

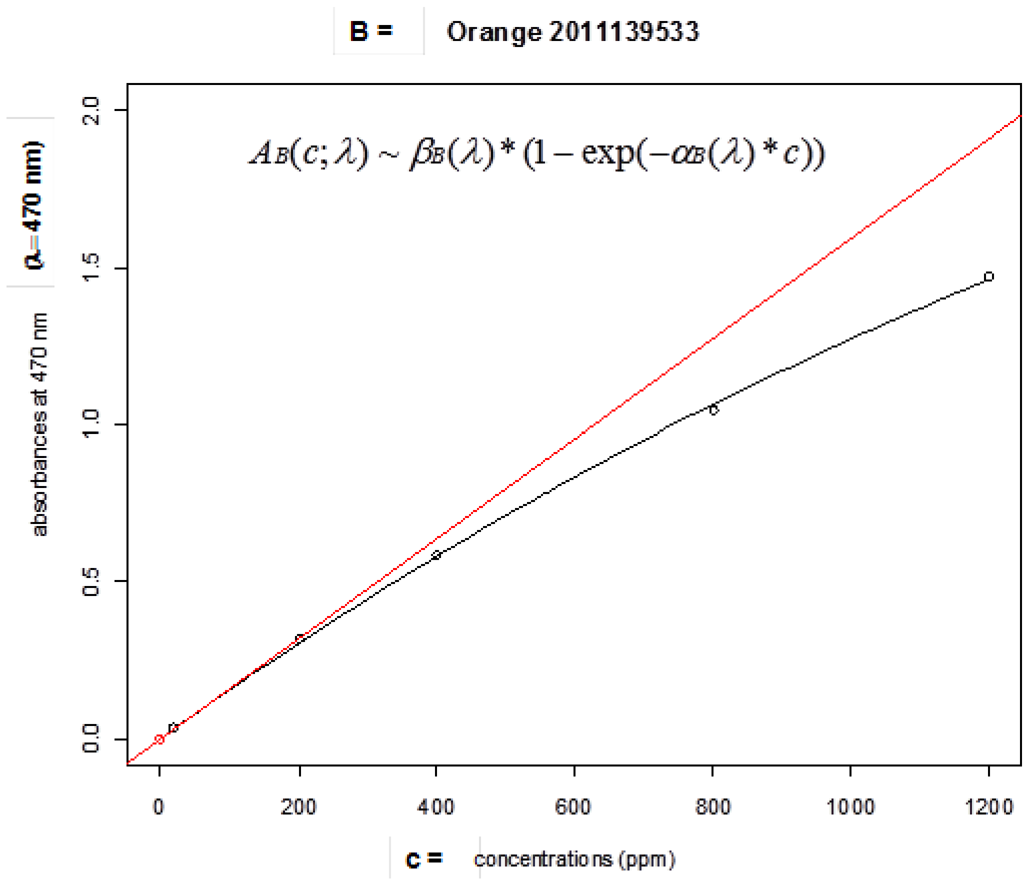



**Figure 10: Required k factor for various concentrations**

The previous figure illustrates the application of the model of absorbance versus concentration for a given wavelength (470 nm) and a given primary colour batch (Orange 2011139533). The points on the graph correspond to the absorbance values measured at the lab (5 values corrected for the influence of the resin). The general form of the model is given at the top of the diagram (the same model with 2 parameters is used for all wavelengths and all basic colours). The use of a model is a preferred approach for point interpolation because it allows partial elimination of measurement noise. The main advantages of the chosen model form are to be almost linear for low concentrations (following thus the Beer-Lambert law) and to be as robust as possible with only two parameters. The adjustment results in calculating the values of 80 coefficients (2 per wavelength interval) for each base colour batch.

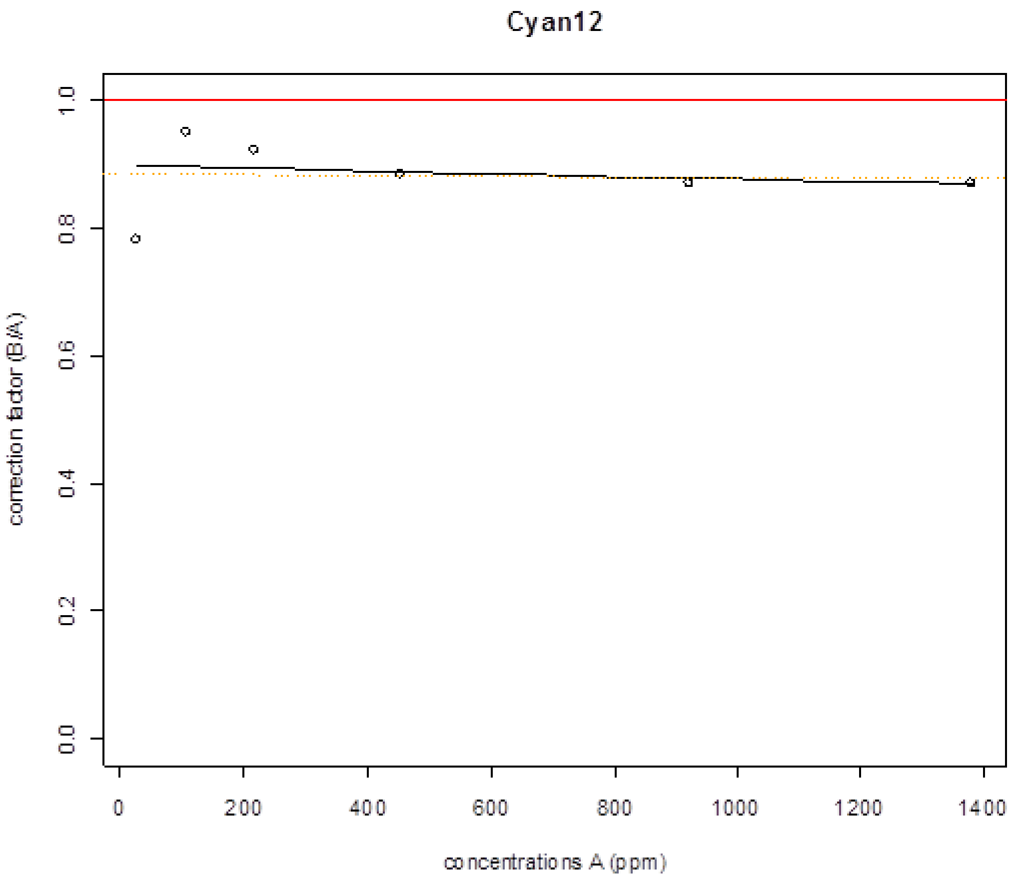



**Figure 11: Application of the model of absorbance versus concentration for a given wavelength**

The next figure corresponds to a change of the cyan colour, from “cyan 1” to “cyan 2” (also noted in a more general form “A” and “B”). The computation is based on the two corresponding sets of loading spectra obtained at Milliken’s lab. The diagram below shows the almost linear evolution of k (solid black line) on the concentration range 0-1400 ppm. In red we have plotted the ideal constant (meaning no adjustment is necessary). The horizontal axis corresponds to the concentrations of the old batch, “cyan 1”.

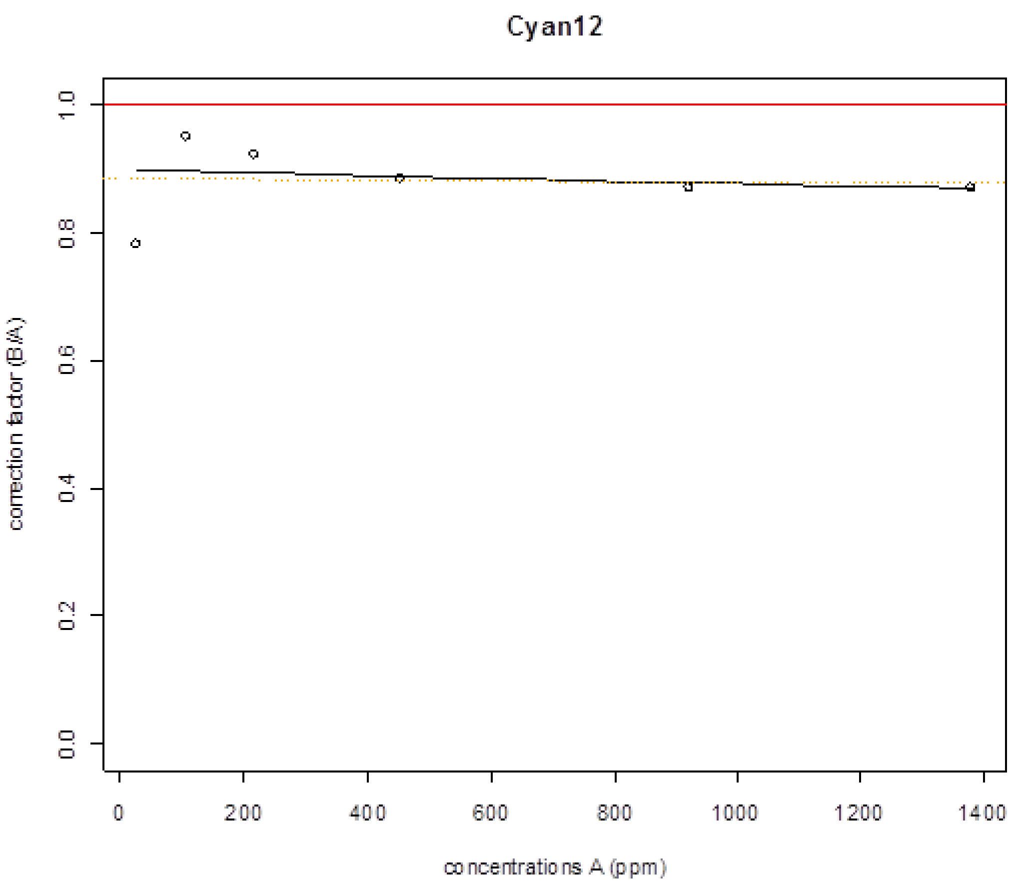



**Figure 12: Change of the cyan colour**

The points plotted in this diagram were obtained by searching, for each of the spectra actually measured on the new batch, the “closest” spectrum in the three-dimensional model based interpolation of the old batch. We thus got for each concentration in B (“cyan 2”) an associated value c in A (“cyan 1”). These values allow us to plot a point with the coordinates**.** The dotted line is the regression line for these points.

*Remark 1:* on the example above we see a concentration of 1400 ppm for the batch A. It is the concentration required to reproduce a spectrum similar to the one of the batch B at 1200 ppm. Since the concentration generally does not exceed 1200 ppm, it is obviously an extrapolated value.

*Remark 2:* some points are outside of the black line due to the difference in observations from the model. This difference is high for low concentrations where the colour measurement is imprecise, but is less pronounced in points beyond 400 ppm; effectively demonstrating that no severe consequences result from the unavoidable approximations.

The next diagram shows what difference in perceived colour remains, after performing the cyan primary colour adaptation. The horizontal axis corresponds to concentrations in the new batch.

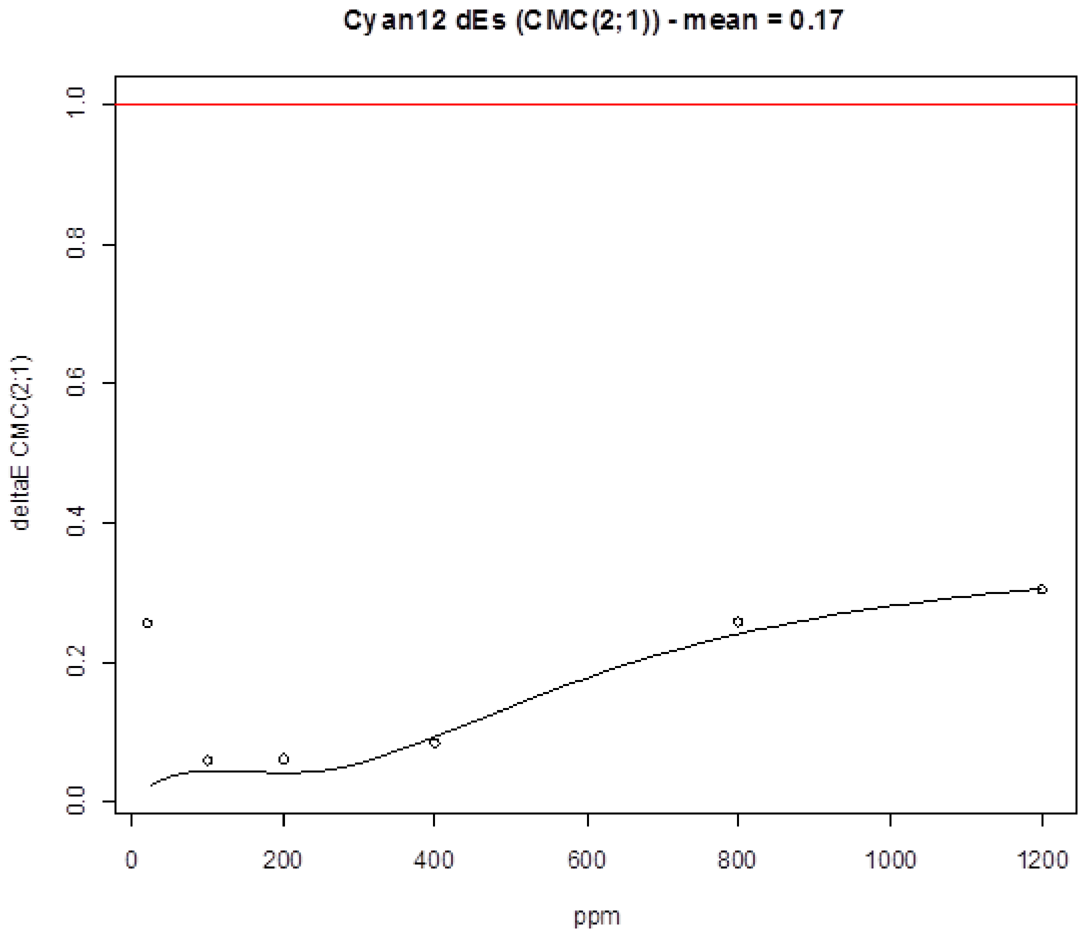



**Figure 13: Difference in perceived colour after adaptation**

The connection between this Delta E and that of any mixture containing that component is not trivial. At least, if the deviation between consecutives batches of a given basic colour mainly concerns the intensity and less the colour (this is our assumption), then the Delta E of the mixture will be lower than that of the component which has changed.

## *6.4 Factory Model*

### 6.4.1 Meta Modelling System

The approach used to develop the TexWIN Factory Model bases on the process model and principles of the 'Grundsätze ordnungsmäßiger Modellierung' (rules of orderly modelling). The process model consists of five steps describing the systematic development of a model starting from the target definition up to the implementation and analysis of the models. The same steps can also be applied to meta-modelling with slight modifications.

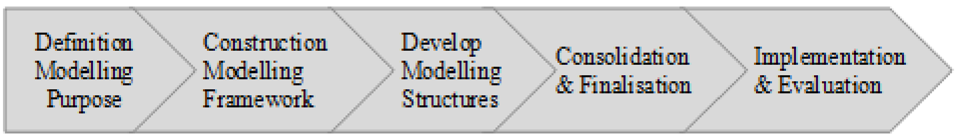



**Figure 14: Process steps of the Smart Network Modelling Method development**

### 6.4.2 Definition Modelling Purpose

The first step, the definition of the modelling purpose, describes the identification of the general constraints, which should be applicable for the TexWIN Factory Modelling Method. The following important constraints have been set during this step:

**Problems covered:** The TexWIN system is a very complex system with many possibilities for adjustments. Also the environment for the TexWIN system is varying from factory to factory. Therefore the modelling method should assist the following topics:

- Define / adapt the resources available in the factory
- Define / adapt the products
- Define / adapt the materials
- Define / adapt the production processes
- Define / adapt the data structure for the resources, products, materials and processes
- Define / adapt the rules for the CBR adaptation
- Define / adapt the rules for factory optimisation

The modelling should therefore enable an easy description of a factory for the TexWIN system.

**Target group:** There are various target groups dealing with the description of the TexWIN system. A first group are consultants installing and (pre)configuring the system. They are experts for the system. A second group is the development department of factory. They predefine the resources and the production processes of the factory. A third group are the master craftsmen. They refine the description delivered by the development department and change / add adaptation rules. The last relevant group is the factory management, with the demand to adjust / change the optimisation criteria for the factory.

**System boundary:** The modelling should only describe TexWIN system internal elements. Not all configuration elements are described, but the ones that could change regularly like products or resources. It is also not planned to describe the interfacing to external systems.

**Modelling language:** The characteristics of a modelling language are directly deduced from the constraints above. The target groups are affected in their daily work by on the one hand very detailed information about an element and on the other hand with highly aggregated information often presented in a graphical way. Therefore the information stored in a model ranges from a meaningful name of an object up to objects with a long list of attributes to be filled. Therefore the modelling language needs a graphical presentation for a quick human interpretation as well as structured computer-readable presentation for further use in the TexWIN system.

### 6.4.3 Construction Modelling Framework

The basis of the TexWIN Factory Model is the “Data Model”. All other models are dependant of this one. The “Machine Resource Model”, the “Product Resource Model” and the “Material Resource Model” describe the TexWIN relevant resources of a factory. With the described resources the production sequence can be described in the “Production Sequence Model”. The “Adaptation Rule Model” is used to define data adaptations with the corresponding conditions. The last one ("Optimisation Model") defines the optimisation rules used by the TexWIN system. The figure below illustrates the overall structure of the modelling framework with all basic model types.

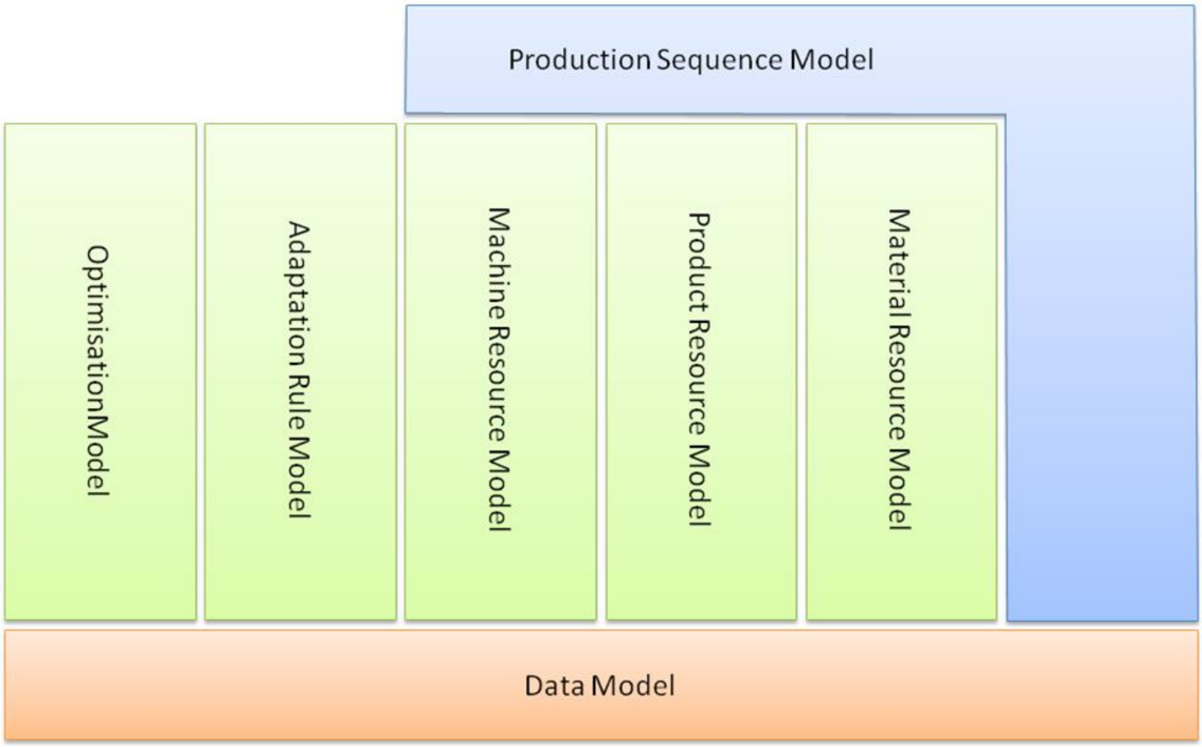



**Figure 15: Framework structure for the TexWIN Factory Modelling Method**

### 6.4.4 Develop Modelling Structures

The third step is the development of the modelling structures. The framework with its model types defines in principal seven modelling subjects, which are dependant.

All the modelling elements are linked with data structures. In the "Data Model" the data structures can be described. The "Material Resource Model" describes the material used in a factory. This description will be used in the "Production Sequence Model" to identify suitable material and also to associate a specific data structure with a material or material group. The "Product Resource Model" describes the products realised in a factory. This description will be used in the production process model to identify a target product and also to associate a specific data structure with a product or product group. The "Machine Resource Model" describes the available machinery in a factory. This description will be used in the production process model to identify suitable machinery and also to associate a specific data structure with a machinery or machinery group. The "Production Sequence Model" describes all valid production processes in a factory. It combines and orchestrates all the resources needed to realise an article or product group. It defines the suitable ways of production, which can be used. This model is the core input for the optimisation of the production on factory level. The CBR system of the production unit controller will be extended by adaptation rules. The "Adaptation Rule Model" enables the description of conditions and rules applicable for certain data structures.

### 6.4.5 Consolidation & Finalisation

The fourth step is the consolidation and finalisation of the modelling. The TexWIN factory modelling method has been worked out the technical and scientific partners. The development process was characterised by the use of the spiral model for all phases except the first one. During various discussions consolidated version of the modelling method has been elaborated. The criteria applied to the TexWIN Factory modelling method during the ‘Consolidation & Finalisation’ phase followed the six principles stated in the rules of orderly modelling. These principles have been elaborated for modelling but can also be applied to meta-modelling.

**Principle of correctness**: This principle requires that the model represents the essential characteristics of the real world object that means for the TexWIN Factory modelling method to describe the core elements (machine, material, product, production sequence, data structure, adaptation rules and optimisation parameters). The final modelling method is fulfilling this principle.

**Principle of relevance:** A model representation of the real world is never describing all aspects of the modelled object. The modelling purpose is important to decide if an aspect of the real world has to be described in the model or not. If it is necessary the principle of correctness is very important for that aspect.

**Principle of economic efficiency:** Beside the principle of relevance this principle is directly influencing the model representation. This criterion states that a balance between the level of detail and the effort to get the required information has to be found. Examples for requests contradicting this principle are extensive description of data structures, description of interface structure (this one also contradicts the principle of relevance.

**Principle of clarity:** This principle covers aspects like readability and clearness of models. The implementation of the TexWIN Factory modelling method respects it by e. g. using clearly understandably symbols and clear definitions of the elements.

**Principle of comparability:** It means that it must be possible to compare models with other models realised with different modelling methods. This principle could only be realised partly due to the non-existence of comparable modelling methods. Single aspects could be compared with other modelling methods, e. g. the “Data Model” approach.

**Principle of systematic design:** The last requirement to fulfil all principles is the systematic design of the modelling method. Following the process model of Becker this demand is automatically satisfied.

## *6.5 Factory Coordination*

The factory coordinator is the software that will coordinate among themselves the parts composing a company to reproduce by a computer the typical dynamics of a manufacturing factory.

From a purely conceptual point of view you can see the factory coordinator as a set of rules applied to transform a raw product into a finished product.

It is best to make clear that while the factory coordinator implements these rules regardless of their actual goodness from the point of view of implementation, the factory optimizer is simply a set of rules, practices, routes that are implemented simultaneously and in harmony with the factory coordinator to improve its quality, speed and cost of production.

Hence:

- factory coordinator = rules and links between the business elements needed to produce a finished product

- factory optimizer = rules and links overlapped to the normal process (factory coordinator) in order to optimize the processes already put in place

The factory coordinator is a software component almost coincident with a workflow engine; it differs from it only for the fact that its task is not limited to mere execution of the workflow, but has the additional task of selection of the correct workflow based on a well-defined cursor.

To better understand this situation it is appropriate to reconstruct a kind of history since the start of the program until the end of the first product.

1. The factory coordinator receives via the 'START NEW BATCH' service the order to perform the processing of a new batch-cursor.
2. The factory coordinator selects a suitable workflow model according to:
   - Raw material contained in the batch-cursor
   - Working urgencies
   - Type of finished product to be produced
3. The execution of the workflow begins by entering the batch into the first buffer (the first intermediate storage point)
4. As soon as the following machines are work discharged, part of the material deposited in the previous buffer-storage point is taken to be processed
5. The batch-cursor moves from the buffer-storage point to the first CHOOSER
6. The CHOOSER recalls the 'Machine Room' service in order to understand which machines are able to work the product
7. The CHOOSER sends the batch to a PUC
8. The PUC works the batch-cursor and sends it to the next step, that will be a buffer-storage point
9. The next step is performed as if it re-begins from step 4

It is useful to make clear that this apparent linearity actually may be dramatically changed from a variety of factors not currently considered by the factory coordinator:

#### 6.5.1.1 Conditional execution step

In the running of the workflow, the cursor can meet some steps that lead to significant variations of the normal production process.

These steps will analyze the data contained within the cursor itself (material properties, processing history, priority, etc.) and according to certain values the continuation through different phases will be required.

It is likely to encounter in reality these steps, especially during the running phases of finishing processes because they are the phases with higher variability.

#### 6.5.1.2 Optimization step

Just as the previous step these steps will optimize the workflow, or more properly optimize the parameters to run services associated with it depending on certain values in the cursor.

These steps can be present with forms and contents even extremely different from each other so they can be represented as simple conditional blocks up to real subworkflow able to vary in depth the main flow. The analysis of these blocks is under the responsibility of the factory optimizer

### 6.5.2 Structure

The factory coordinator can be represented as a series of paths composed by crossroads and optimizations in which the cursors-materials move, following precise rules.

Often the cursors meet progress steps that will change the data within the cursor itself enriching it with new information and distorting its meaning.

It is good to make clear that in this much generalized landscape the boundaries of competence of the factory coordinator appear blurred or otherwise difficult to be identified. It is difficult to understand if and which skills are under the responsibility of the factory coordinator and which ones concern other software components, such as the corporate ERP or Production Unit Controller (PUC).

These blurred perimeters are not a limitation as it may seem but rather, a great advantage that unequivocally shows the versatility of this technique. A concrete example of this is well documented by the CHOOSER service (step which evaluates the best machine from a subset of different machines but having the same nature).

Some advanced ERPs are not limited to the identification of the type of machine through which to send the semi-finished product, but they point with absolute objectivity at the machine to be used at that particular time to reach a certain goal.

Within the workflow the CHOOSER will always be present by exposing the same input XML and the same output XML, like a proxy pattern. In practice it appears to the workflow engine as if it were exactly a PUC service. In reality, the internal software architecture will vary significantly depending on the functionalities provided by the corporate structure and in this specific case from the ERP. In practice, if the ERP would already provide a recognition system of the best machine, the CHOOSER service would be limited to a simple wrap, for example a software component that limits itself to delegate the real work to another entity

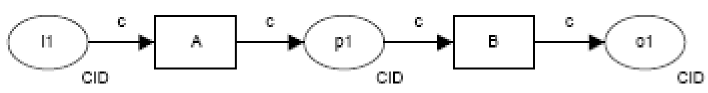
In the second case the CHOOSER will implement internally a more or less complex algorithm, able to identify the best machine on which to work the material. How many CHOOSER will be present in TexWIN? Hypothetically only one, but this does not mean that the number of CHOOSER can be extremely higher and can also include components that appear identical but with very different internal algorithms.

Not only. In the more complex case the workflow engine may meet during its execution even one wrapper step, that exposes the same input and output but in reality delegates the whole amount of tasks to other steps internally present.

### 6.5.3 Flow Structures

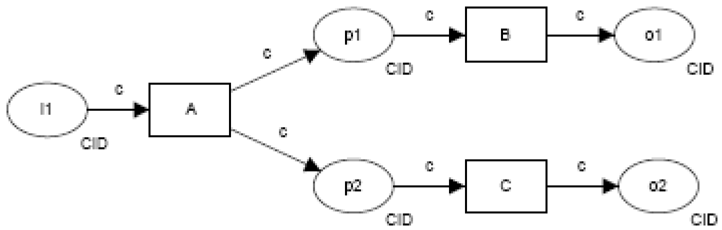
#### *6.5.3.1 Sequence*

A task in a process in enabled after the completion of a preceding task in the same process.



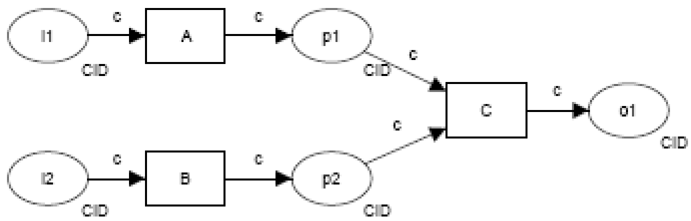
### 6.5.3.2 Parallel Split

The divergence of a branch into two or more parallel branches each of them execute concurrently.



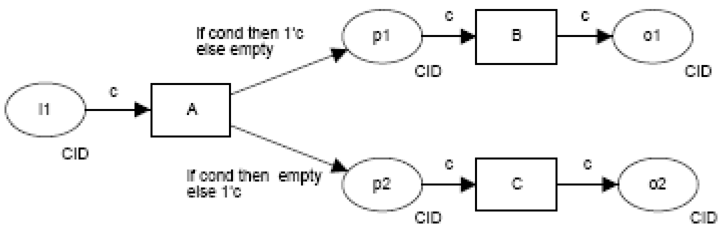

### 6.5.3.3 Synchronization

The convergence of two or more branches into a single subsequent branch such that the thread of control is passed to the subsequent branch when all input branches have been enabled.



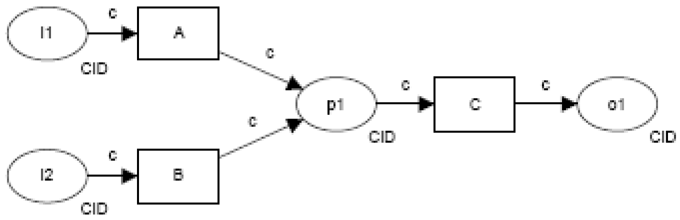

### 6.5.3.4 Exclusive Choice

The divergence of a branch into two or more branches such that when the incoming branch is enabled, the thread of control is immediately passed to precisely one of the outgoing branches based on a mechanism that can select one of the outgoing branches.



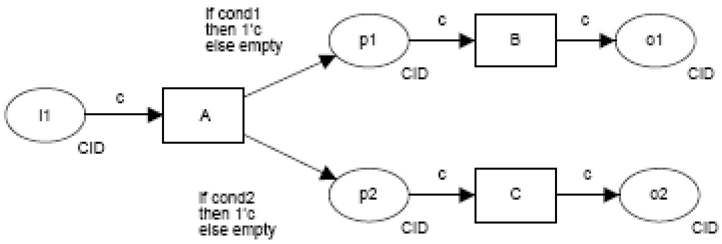

### 6.5.3.5 Simple Merge

The convergence of two or more branches into a single subsequent branch such that each enablement of an incoming branch results in the thread of control being passed to the subsequent branch.



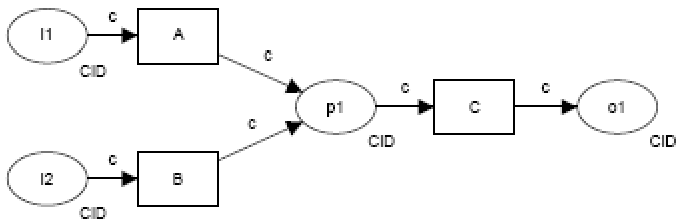

### 6.5.3.6 Multi Choice

The divergence of a branch into two or more branches such that when the incoming branch is enabled, the thread of control is immediately passed to one or more of the outgoing branches based on a mechanism that selects one or more outgoing branches.



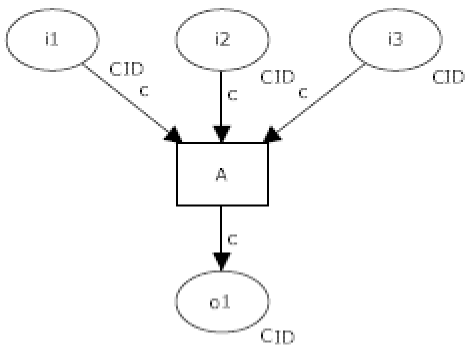

### 6.5.3.7 Multi Merge

The convergence of two or more branches into a single subsequent branch such that each enablement of an incoming branch results in the thread of control being passed to the subsequent branch.



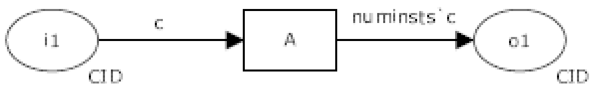

### 6.5.3.8 Generalized AND-Join

The convergence of two or more branches into a single subsequent branch such that the thread of control is passed to the subsequent branch when all input branches have been enabled.



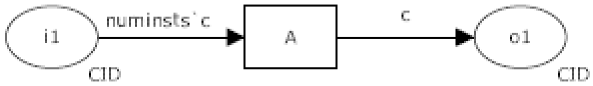
#### 6.5.3.9 Thread Split

At a given point in a process, a nominated number of execution threads can be initiated in a single branch of the same process instance.



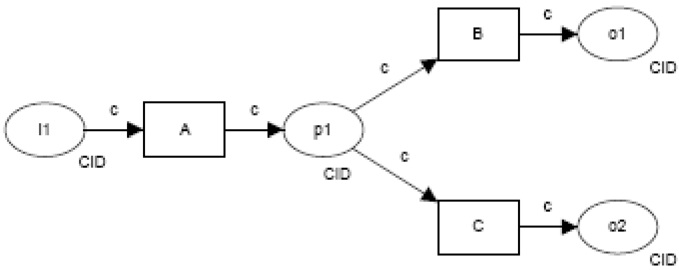

#### 6.5.3.10 Thread Merge

At a given point in a process, a nominated number of execution threads in a single branch of the same process instance should be merged together into a single thread of execution.



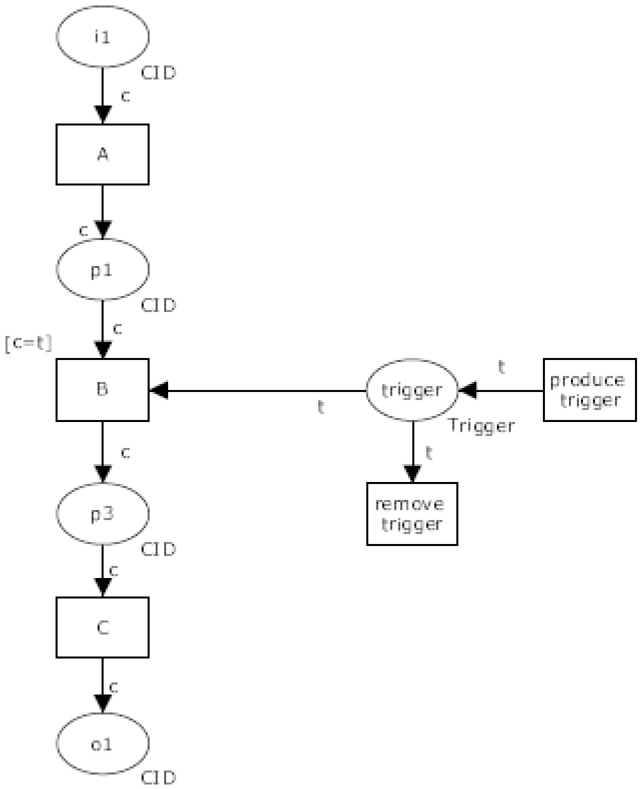

#### 6.5.3.11 Deferred Choice

A point in a process where one of several branches is chosen based on interaction with the operating environment.




#### 6.5.3.12 Transient Trigger

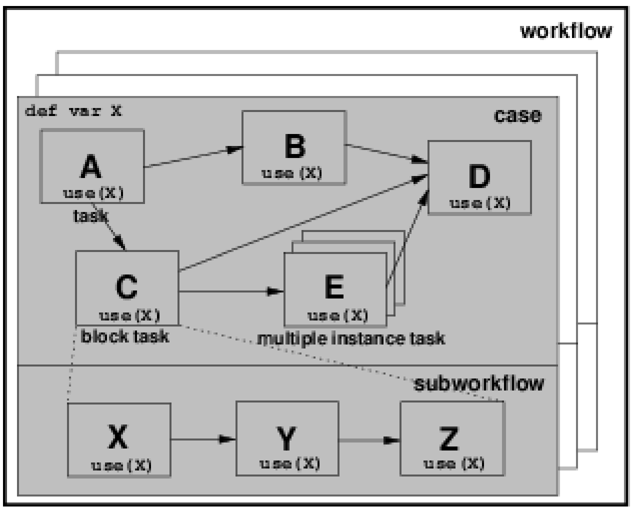
The ability for a task instance to trigger an activity by a signal from another part of the process or from an external environment.




### 6.5.4 Data Structures

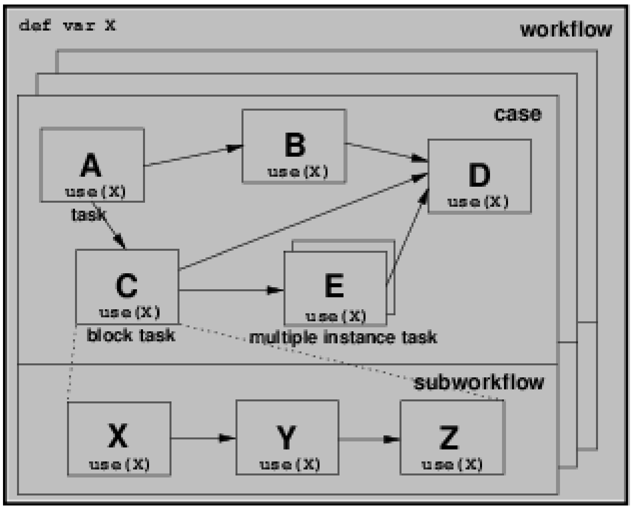
#### *6.5.4.1 Case Data*

Data elements are supported which are specific to a process instance or case. They can be accessed by all components of the process during the execution of the case. Data elements defined at case level effectively provide global data storage during the execution of a specific case. Through their use, data can be made accessible to all process components without the need to explicitly denote the means by which it is passed between them.



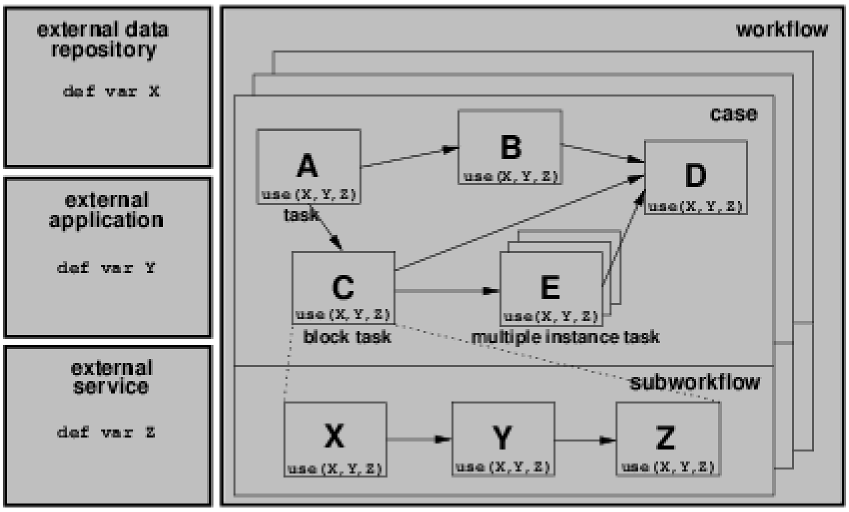

#### *6.5.4.2 Workflow Data*

Data elements are supported which are accessible to all components in each and every case of the process and are within the context of the process itself. Some data elements have sufficiently broad applicability that it is desirable to make them accessible to every component in all cases of process execution. Data that falls into this category includes start-up parameters to the operating environment, global application data that is frequently used and production information that governs the potential course of execution that each case may take.




### 6.5.4.3 *Environment Data*

Data elements which exist in the external operating environment are able to be accessed by components of processes during execution. Direct access to environmentally managed data by tasks or cases during execution can significantly simplify processes and improve their ability to respond to changes and communicate with applications in the broader operational environment.




## 6.6 *Factory Optimisation*

### 6.6.1 Hierarchical Control Structure

The TexWIN-System consists of a Factory Controller and a Production Unit Controller. They form a hierarchical control structure with three control layers. The first layer (machine internal control) was not subject of the TexWIN project.

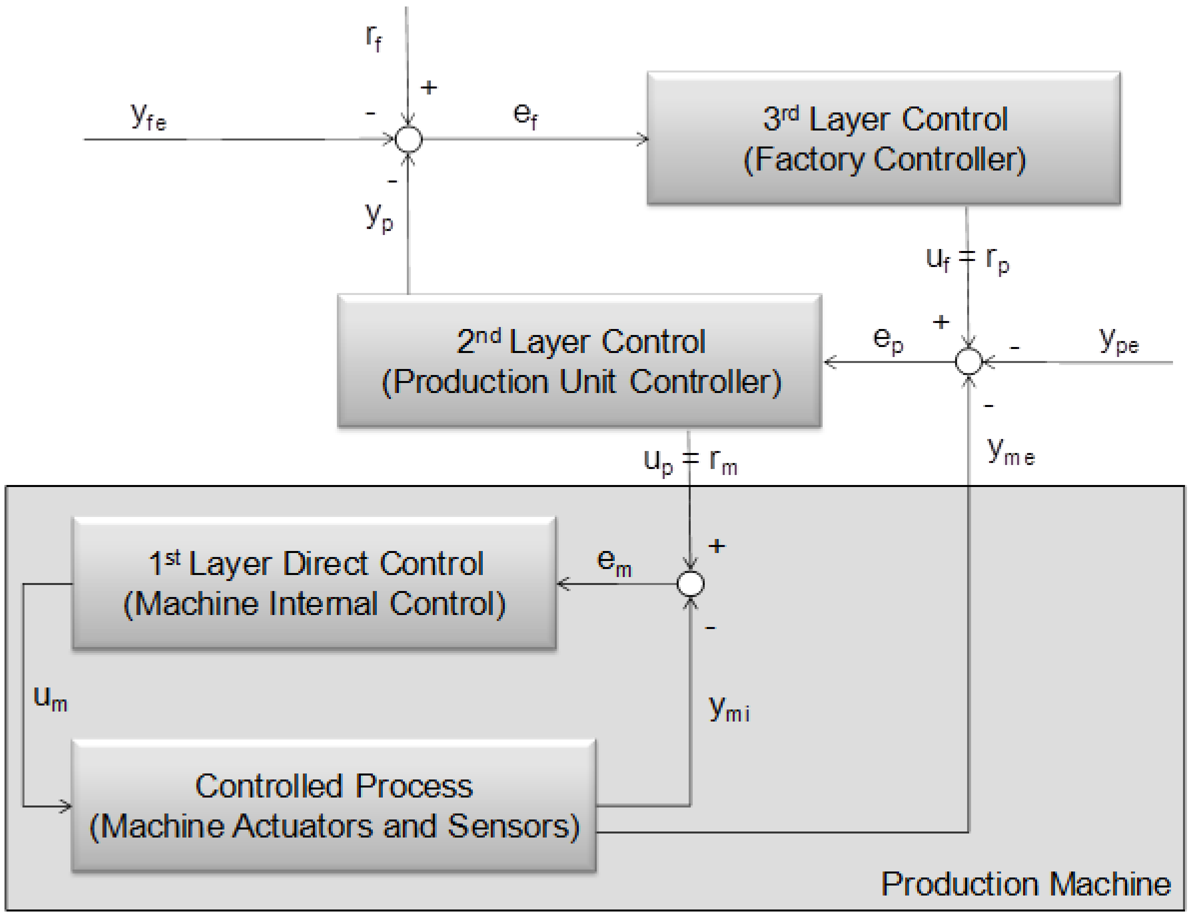



**Figure 16: Hierarchical Control Structure of TexWIN**

The blocks (Factory Controller and Production Unit Controller) cooperate in both forms of use, the production order scheduling with the Factory Optimisation module in the leading role, and in the execution phase the leading role moves on to the Factory Coordination module. The figure below shows the logical architecture of the control structures formed by the TexWIN modules.

Besides the collaboration with several Production Unit Controllers, the modules of the Factory Controller interact during the fulfilment of the current task. For example in the execution phase the Factory Coordination module initiates a new more restricted optimisation, if there are unforeseen disturbances, to face changed constraints caused by the feedback of the previous system.

The Factory Coordination module will coordinate the Production Unit Controller of each process step in order to achieve an overall optimum of productivity and quality at factory level. Each Production Unit Controller will receive quality information of the Production Unit Controller of the preceding step(s). This information will be integrated into the CBR process, in the sense of a feed-forward-control. Thus it is possible to align the local machine settings according to the quality of the preceding process steps.

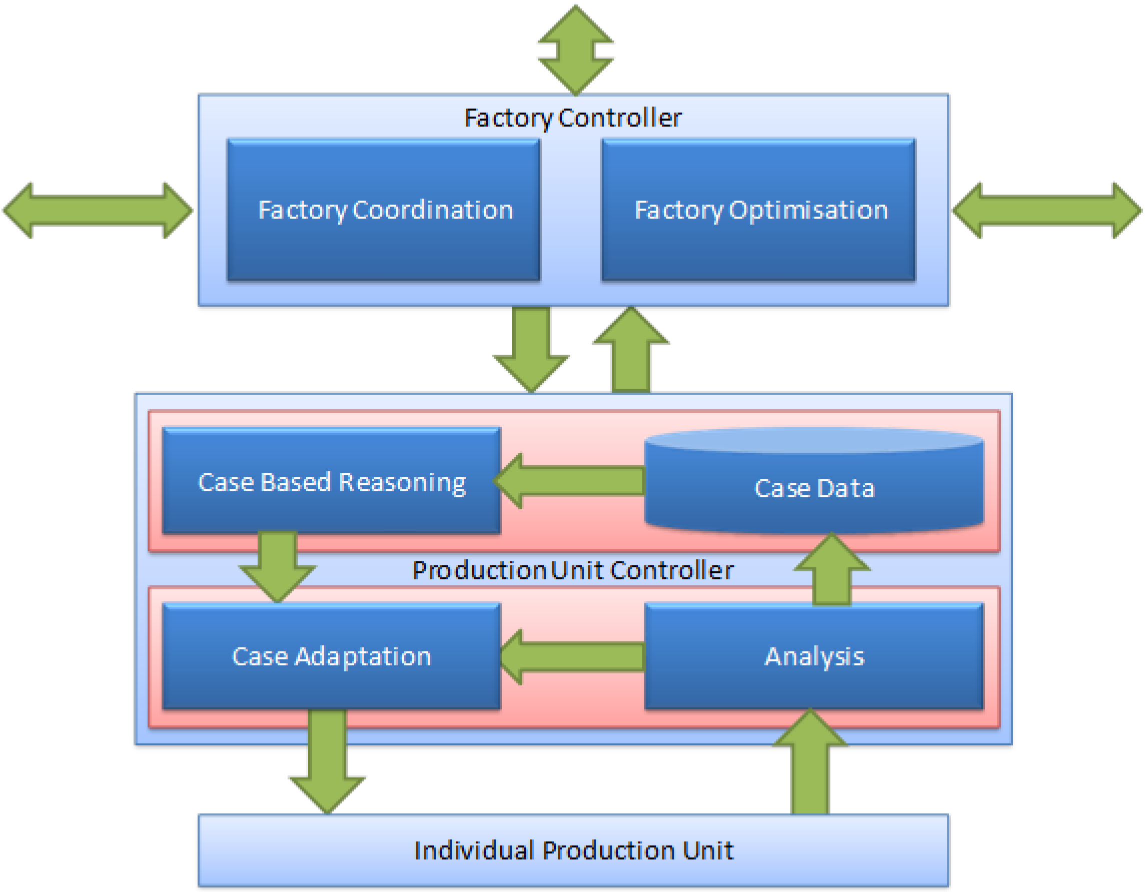



**Figure 17: Logical Architecture of TexWIN system**

The Factory Optimisation module provides algorithms and methods to calculate an optimal sequence and selection of process steps and machine types to reach the specified outcome. Besides the above described optimisation functionality during the running production process (between process steps) the more important job of the Factory Optimisation module is the prediction/selection of the best sequence of the process steps. Such an approach is necessary if there are more than one possible ways to reach a specified goal. For that reason the Factory Optimisation module uses a top-down optimisation strategy which can use genetic algorithms for instance.

### 6.6.2 Second Control Layer

#### *6.6.2.1 Task*

The second control layer consists of an automated Case Based Reasoning system and the related Case Data base. First of all the automated CBR system enables structured retaining and externalising of existing process experience/knowledge e.g. machine settings, recipes. Beyond that the strength of CBR systems is the retrieval of information to support their reuse.

This methodology allows the consideration of feedback from the production operators to optimise the current running product based on the experience with the same or similar products. The automated CBR system uses an ontological knowledge base which contains an application specific case description and application specific similarity functionality. The similarity functionality enables a simplified progress of the CBR routine because the predefined similarities will be automatically evaluated and prepared for further use either in direct reuse or in an adapted form. The cases will be stored in an abstracted form in the Case Data base.

### 6.6.2.2 Optimisation Problem

The textile production chain is a discontinuous production composed by various production steps. They have to be monitored and managed by the company. The schedule of orders is fixed. Now during production an order can run faster or slower than planned. This can destroy the timing of the schedule. For example if a weaving machine is faster than expected the good has to be stored in a buffer because the following resource is still in use by a previous order. Another example would be that a weaving machine has lots of stops and is therefore slower than expected. The following resource is now waiting for the order to arrive and is not productive.

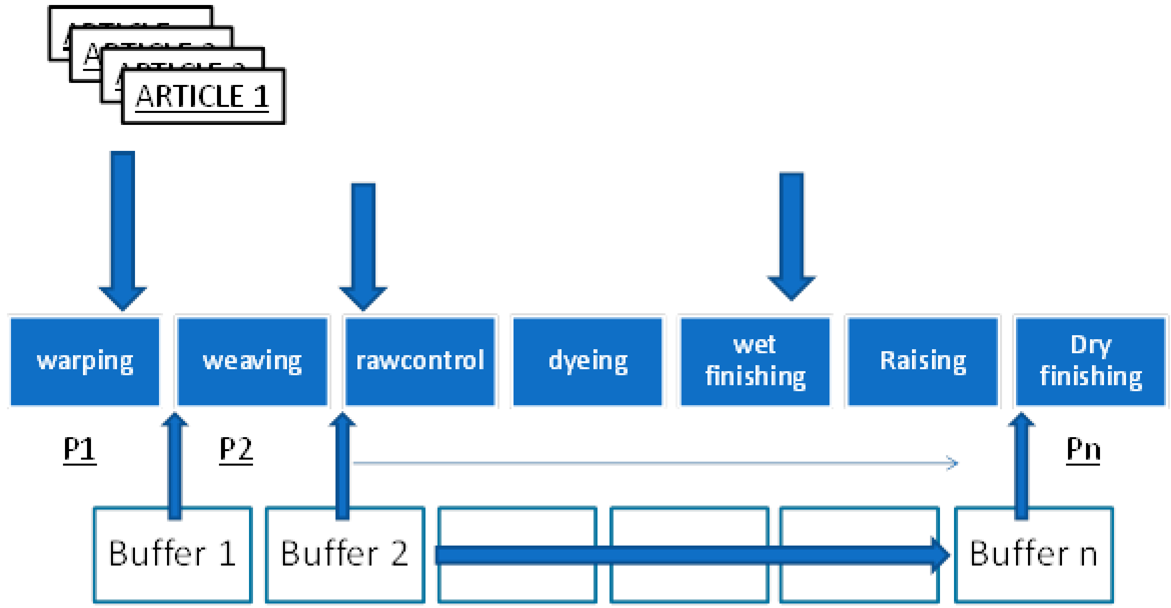



**Figure 18: Simplified Optimisation Problem Second Control Layer**

TexWIN will try to reduce the number of waiting resources due to empty buffers and also due to overflowing buffers. The optimisation will be done based on machine feedback optimising the use factory resources. Unnecessary waiting times will be avoided by relocating resources considering the current demand of the orders.

### 6.6.2.3 Optimisation Strategy

The optimisation strategy for the second control layer will allow the realisation of the following optimisation goals:

- Reduce waiting times due to delayed previous production
- Reduce waiting times due to overflowing of buffer in the preparation area of the next production step

To realise these goals two different solutions at two different levels have to be combined. The first solution will be called “a posteriori” and the second one “a priori”. For both solutions a upper (nearly full) and lower limit (nearly empty) for the buffer in the preparation area of a production step has to be defined (see below).

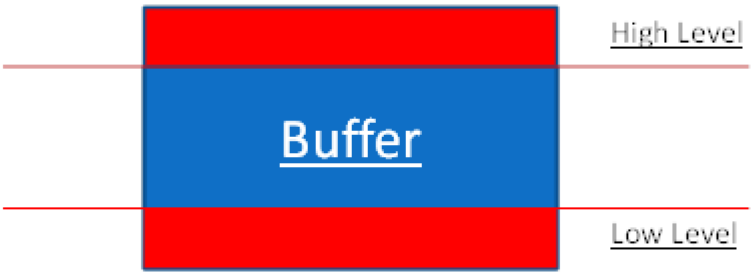



**Figure 19: Buffer with upper and lower limit**

In the first solution each buffer has to be monitored periodically. If the limit has been reached a message will be created and send to the person responsible for planning. This person can then decide if rescheduling is required. For rescheduling the optimization of the third control layer will be started.

The second solution “a priori” is not waiting for a buffer message but tries to anticipate the status of the buffer in the near future. The state of a buffer will be simulated based on current machine information like velocity or efficiency (see below). The status of all buffers will then be analysed on process level.

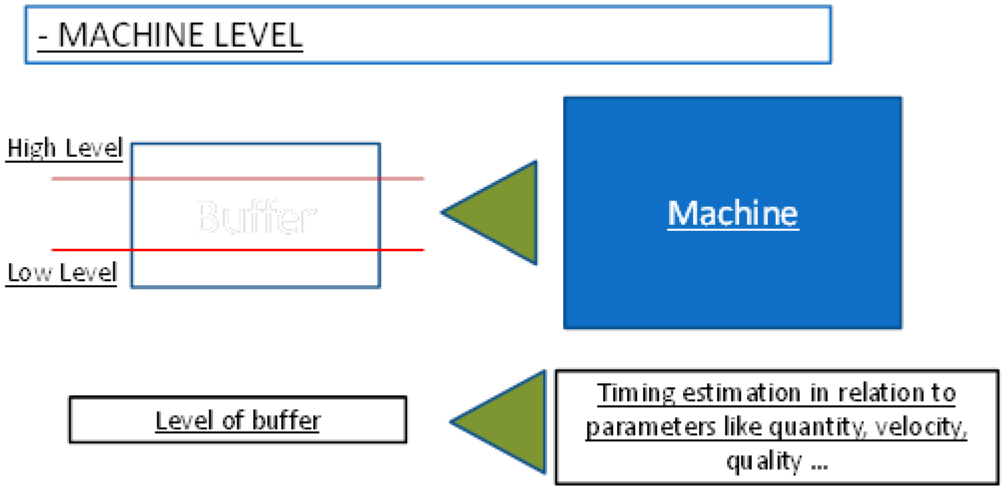



**Figure 20: Buffer simulation on machine level**

For the TexWIN system a simplified calculation for buffer estimation will be used. The core parameters are the speed, the set-up time and the total length to produce. Additionally the efficiency of the individual machine is also part of the calculation. The machine efficiency can be identified by the TexWIN CBR component (auto adaptive) or by a fixed formula identified for each machine by analysing past products. With this formula we can estimate the time of production and the level of the buffer.

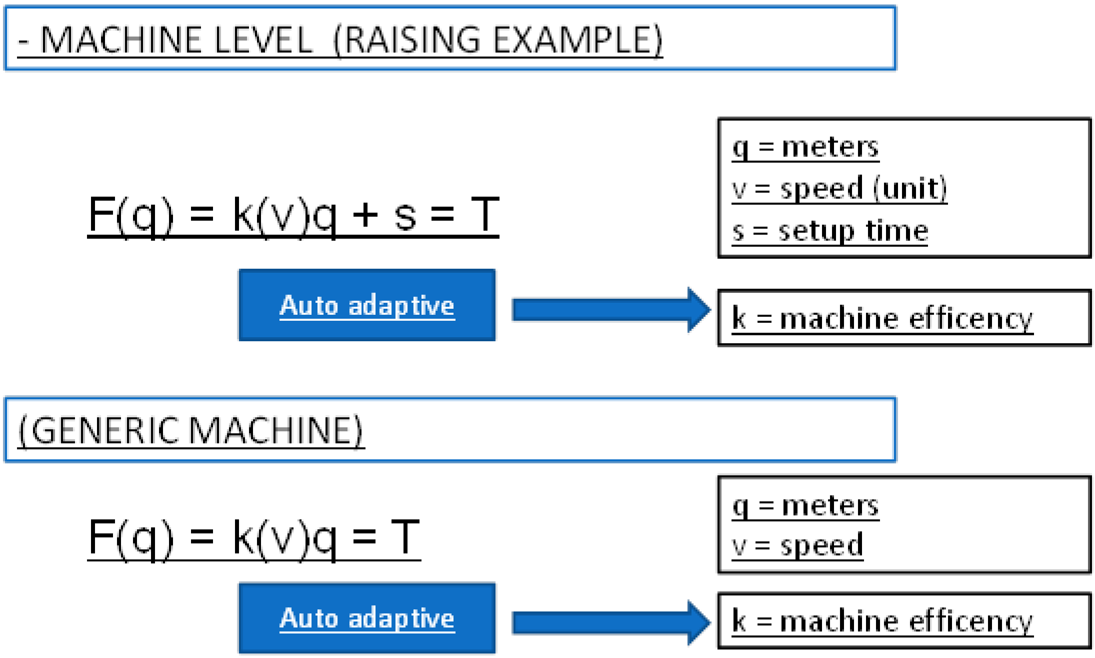



**Figure 21: Formula for prediction of machine buffer level**

Above you see the formula for a raising machine and for a generic machine. Used is the total length (q), the speed (v), the set-up time (s). All parameters are order and/or article dependent. The machine specific efficiency (k) is dependent of the speed.

At process level the production time of a product is the sum of the production time of the individual processes and the waiting time in queue. This ideal time value is modified by the efficiency of the department (see below). The efficiency of the department is depending on the operators available, on the complexity of products produced, the climate and many other aspects. It can be identified using the CBR component accessing the experience of the past.

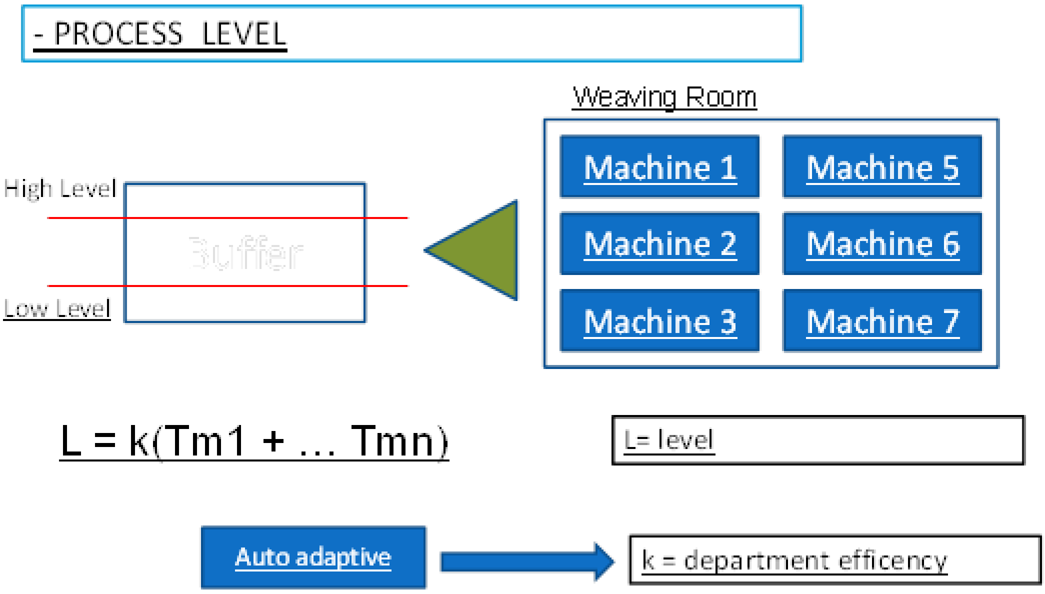



**Figure 22: Formula for prediction of production time**

Both methods can be combined to provide a forecast of production and to identify delays.

### 6.6.3 Third Control Layer

#### *6.6.3.1 Task*

The main tasks of the Factory Controller are the optimisation, harmonisation and coordination of the process chain to increase efficiency of the usage of resources like material, energy, etc.

The original idea was that the Factory Controller Optimisation provides algorithms and methods to calculate an optimal sequence and selection of process steps and machine types to reach the specified outcome. Besides the above described optimisation functionality during the running production process (between process steps) the more important job of the Factory Optimisation module is the prediction/selection of the best sequence of the process steps. Such an approach is necessary if there are more than one possible ways to reach a specified goal.

After an analysis of the possibilities at the industrial partners it proved that there is no flexibility for changing the sequence of process steps. The original idea of optimising the sequence of process steps therefore lapsed. But during this analysis another optimisation demand has been exposed. The new optimisation problem will be described below.

#### *6.6.3.2 Optimisation Problem*

During the analysis it has been shown that the strategies used planning and scheduling are considering very few information about production. There is a pool of order that will be distributed among the available machineries (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Sophisticated algorithms are calculating best solutions for this problem. It proved that not the capabilities of the scheduler are limiting the quality of optimisation but the information used for the optimisation algorithm. For example the duration of an order is calculated from the base product data, which could be significantly different than the real production time on the various machines. Due to the different capabilities, maintenance status, operators, raw material and climate conditions the performance of each machine can be very different from the expected ones. Without considering the performance of machinery the available resources cannot be used efficiently. The scheduler should therefore consider the current situation of the factory and not theoretical values from the ERP system.

Additionally the optimisation for best use of machinery is not the preferred one. If $CO_2$ production has to be reduced other machines could be better than the best running ones in terms of production efficiency. Therefore additional information has to be provided to the scheduler for optimisation. Most state of the art schedulers are capable to handle additional input for optimisation. This enables to align the optimisation process more to the demand of the company policy.

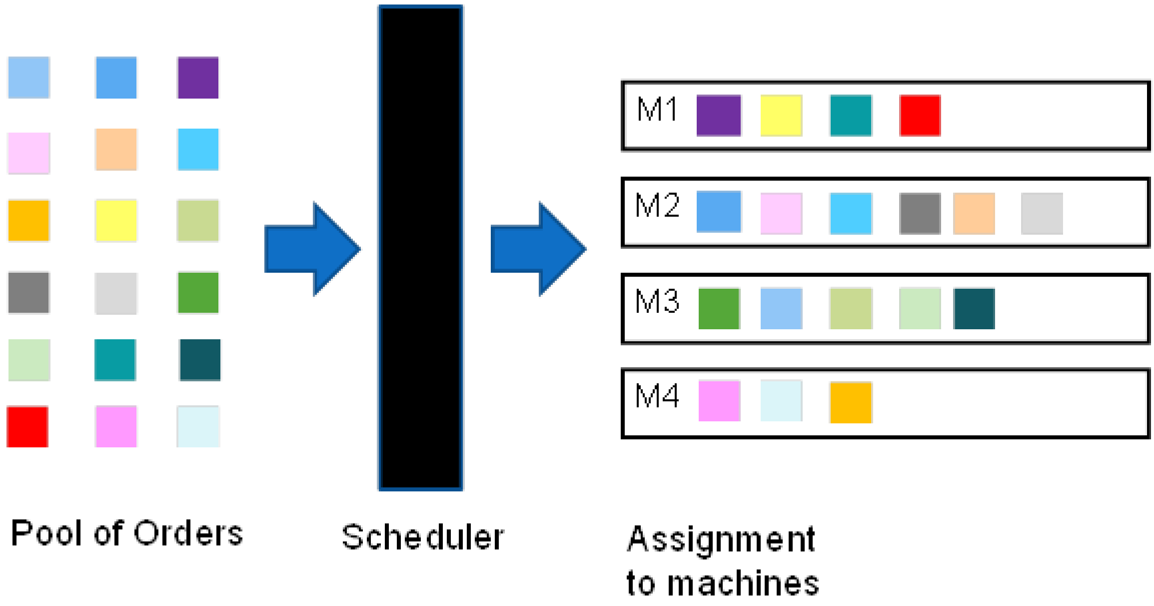



**Figure 23: Simplified Optimisation Problem Third Control Layer**

For the TexWIN project the consideration of the current production capabilities for each order is in the main focus. The optimisation based on energy efficiency or $CO_2$ reduction will be prepared but not realised due to missing data for energy consumption and $CO_2$ production.

#### *6.6.3.3 Optimisation Strategy*

The optimisation strategy for the third control layer will be a flexible structure allowing the realisation of each of the following optimisation goals:

- Maximise quality of the product
- Optimise usage of available material lots (e.g. yarns)
- Minimise process time
- Maximise machine efficiency
- Minimise energy consumption
- Minimise set-up time

To realise these optimisation goals we require a pool of orders and specific information for each possible machine order combination. For example TexWIN has to answer the following questions to the scheduler. “What quality is possible for order 1234 on machine 56?” or “What is the energy consumption of order 4321 on machine 65?” (see also below).

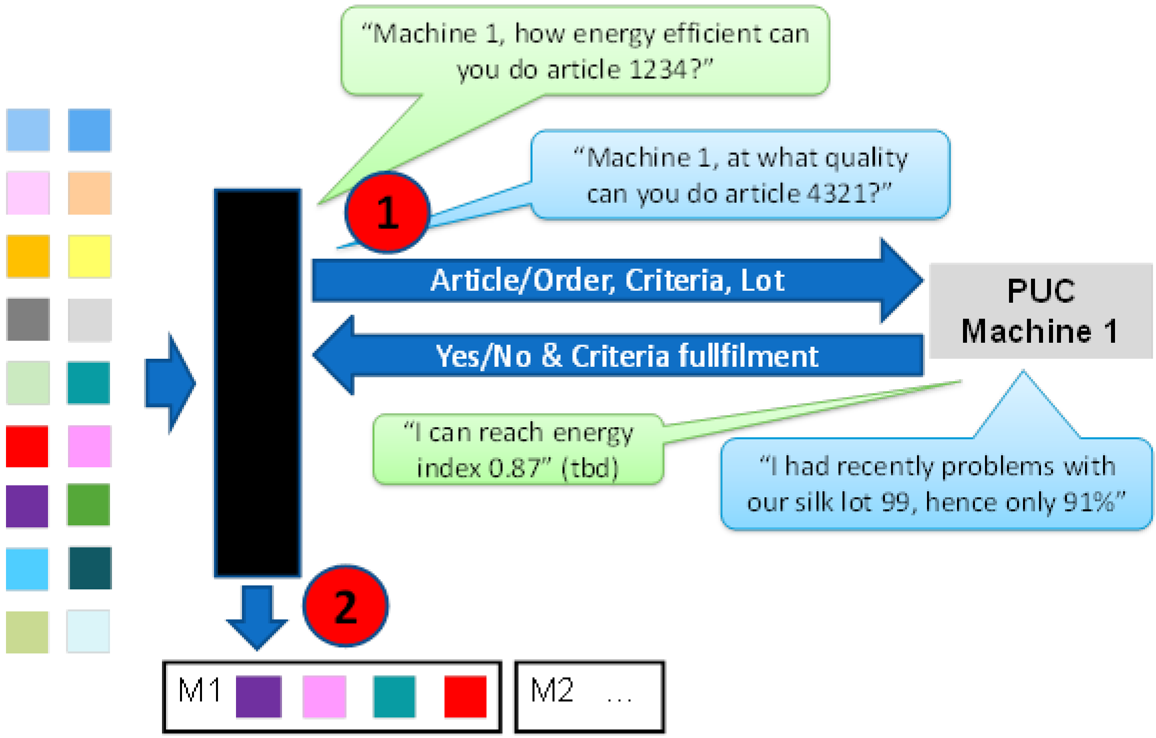



**Figure 24: Example of the TexWIN-Scheduler combination**

In short the scheduler asks for each order the efficiency (e.g. energy consumption, stop times, quality) for each possible machine. With this result the scheduler has a preference list of machines for each order. The scheduler can now optimise following the standard optimisation algorithm integrating the results of the preference list.

The sequence diagram (see below) shows the interaction between the User interface (HMI), the factory controller (FC), the optimizer and the PUC. As shown, the user interface interacts to the optimizer, giving a work plan and expecting a list of ranged work plans. The first interaction is followed by the communication between the optimizer and the factory controller: this is necessary to get the process description. During its life, the optimizer should repetitively involve the PUCs installed on the machines to get the setup estimations based on the order details.

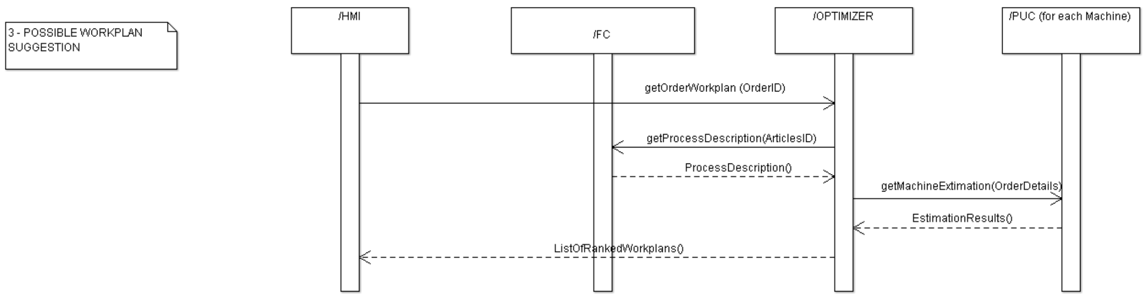



**Figure 25: Sequence diagram for the third layer optimizer**

At first an operator has to keep up-to-date the factory layout through entry forms that modify the information. This is to be thought as an operation that may influence directly the TexWIN software, when the end user will not integrate to its own ERP. When ERP integration is available, the operators will just work normally on their system and the TexWIN event handler will just update automatically its internal factory information through the connector.

The optimization is a batch procedure that uses the factory data from the coordinator. It is used by the production manager, who is in charge to decide where and how a batch should be scheduled for production. The optimizer works as described in the previous chapters and it will supply the machines settings and a list of warnings and suggestions.

The production manager main task is not replaced by the optimization. He will continue to use the ERP to set the production plan according to the machines characteristics, workers availability and delivery dates. But he can use accept the system suggestions to improve the schedule in order to fulfil the objectives covered by TexWIN: efficiency and high quality.

In a few words, the optimization will follow this sequence:

1. An operator enters and keeps up-to-date factory data manually in TexWIN or indirectly through the ERP.
2. The production manager launches the offline optimization
3. The manager reads the settings suggested by the optimization as well as warnings and suggestions on how to avoid problems.
4. The manager decides if to apply the system suggestions and proceed with the normal production scheduling.

Once offline optimization is done, and the production has begun, the production manager still may influence efficiency according the real data monitored from the PUC: it is always possible to adjust the schedule at any time, according to the actual monitored data, as well as failures or other unexpected events. TexWIN continue to support the manager through online optimization.

## *6.7 Communication Framework*

In the middle in-between all the application oriented modules lays the communication framework, which allows all other modules to exchange data and to share information efficiently, without interoperability and communication barriers. As framework TexWIN implemented a service oriented architecture (SOA) based on webservices which are fully specified but also strictly controlled by a common system-wide WSDL description file (TexWINServices.wsdl) and a common data type description (TexWIN.xsd).

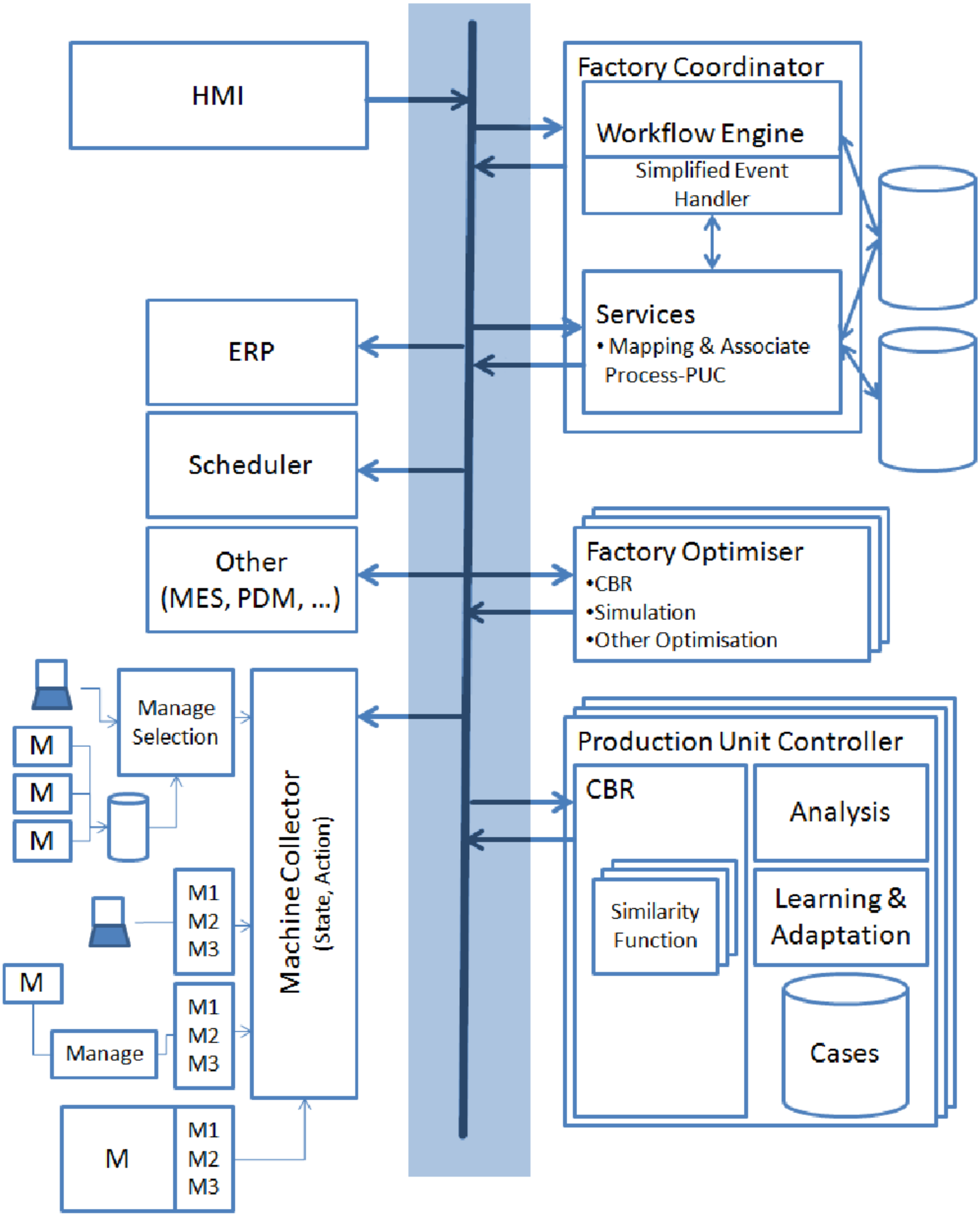



**Figure 26: TexWIN Architecture with Communication Framework**

The complete communication framework of TexWIN relies on a service oriented architecture (SOA) based on webservices which are fully specified but also strictly controlled by a common system-wide WSDL description file (TexWINServices.wsdl) and a common data type description (TexWIN.xsd).

WSDL is a XML format to describe a web service. It allows to specify the location of the service and the operations (or methods) the service exposes to let other components access those services.

A WSDL file describes the following:

- Services available by the web service interface, such as listing names of methods and attribute messages

- Complete description of the data structure and data types of the messages
- Binding information for the transport protocol, such as HTTP and JMS
- Service address to be used when calling it

As such each of the TexWIN software modules can retrieve automatically the complete description of the published web services by connecting to the webserver. For the pilot the main web services are published on the following URL. Remark that this webserver offers separate decoupled instances for each of the partners.

The TexWIN functionality can be described as a sequence of interactions and collaborations between the different TexWIN modules. One sequence consists of multiple phases. Because the TexWIN communication framework is completely implemented as web services, each phase results in at least one inquiry with reply from one TexWIN module to another. Typically TexWIN collaboration starts with a request from the HMI forwarded to the factory controller. The FC either can reply immediately, when all requested information is available within. Else the FC first inquires for further information from an external system or from the PUC before replying.

All TexWIN interaction was designed and documented by means of UML sequence and collaboration diagrams. The UML visualizes the modules and their relationships, including the messages that must be exchanged. A sequence diagram emphasizes the time ordering of the messages.

In this chapter each phase will be explained in detail, with a corresponding extract from the UML service diagram. Each phase is composed of different steps, and each step requires the invocation of a service. For each step is provided:

1. The description of the activity to perform
2. The requester of the service
3. The name of the invoked service proceeded by the name of the component that could provide the service (ex.: FC: getDailyOrderList means that the Factory Controller should provide the service getDailyOrderList)
4. Input and response data for the service.

# 7 Potential Impact

### 7.1.1 *Improvement* in the Textile Industry

#### *7.1.1.1 Qualitative Improvement*

First of all, the TexWIN system improves the use of the available textile technology by enabling the companies to exploit the available resources and capabilities to its maximum effect. The impact depends on the use of resources by the individual companies but an improvement by 5% to 10% could be reached. The project itself doesn't provide new technology. It relies on the available technology within the companies. This is also a benefit of TexWIN because no large investments have to take place.

The TexWIN system has different optimisation modes. One mode is dedicated to the improvement of the product quality. With basic parameters like duration of production or specific machine components the system tries to improve the quality of the product. This is possible within the production process (reacting to bad quality) or from order to order (producing higher quality). The impact on the various companies depends on the starting situation and the target market but reduction of quality relevant errors by up to 20% is possible.

An alternative operation mode is to increase the production efficiency with a given quality. The effect is similar to the production quality. The efficiency can be increased within a production process or from order to order. The impact on production efficiency is depending on the type of machinery and product. The reduction of stop times can reach up to 10% and the increase of speed can result to up to 5% more availability. By avoiding set-up times and reducing stop times the availability of machinery will be increased thus leading to an improvement of the production flexibility without the requirement of new resources. The increase in flexibility is strongly depending on the size of orders, the type of product, and the used machinery.

The increase of quality and production efficiency has a direct impact on the costs of product. Increase in quality means that cheaper raw material can be used to realise the same final product quality. Increase in production efficiency can also lead to cost savings but this is not mandatory. Higher production speed leads to higher output but can also result in higher energy costs. Depending on the used raw material and the production process the costs can be significantly reduced.

More in general, the TexWIN project has a big impact on the management of knowledge within companies. It supports the collection of process and product knowledge in the process development, production and planning. Together with the integration of the various data sources inside a company the knowledge can be exploited efficiently. Especially in textile companies the knowledge of the machine operators are essential for the success of a company in a highly competitive environment. Retiring or leaving people are a big challenge for textile companies. With the TexWIN system the knowledge can be conserved and exploited. The impact of this improved knowledge management leads to better products, higher efficiency and higher production flexibility.

The TexWIN project changes the workflows in the development of new products, the planning of production as well as the production process itself. Steps dedicated to collecting, combining and analysing data will now be replaced by TexWIN activities thus reducing the duration of these activities. The effect depends on the data integration level before TexWIN but a reduction of up to 30% has been reached.

Additionally the quality of data for decision making is much better. This also reduces the number of required feedback loops in product development and in the set-up phase of the production. For example the colour measurement activities at the company Milliken could be reduced by up to 35% (depending on the number of orders from one barrel it could be reduced from 20 measurements to 13 measurements with the new approach). The detailed impact is depending on the organisation of the product development process and the set-up phase.

The improvement of the planning process also has a significant impact on the workflow. By integrating additional information into the planning some set-up activities could be avoided. Depending on the machinery a set-up procedure can have duration of up to 4 hours. In the demonstration case Dyckhoff the number of warp changes (set-up procedure) could be reduced by 10%.

The TexWIN system also integrates a continuous improvement process into the production process. The learning phase in the CBR cycle is the core element for this improvement. Depending on the quality and type of production the impact can be significantly. It directly affects product quality and production efficiency.

The TexWIN system saves the personnel a lot of time dedicated to collecting and analysing data that requires now less time. The personnel have therefore more time to spend in their other activities. This reduces the pressure on each individual worker. Additionally they got better information, which supports them in their decision making. They feel more comfort now with their decisions. The effect cannot be measured directly but on the long term the satisfaction of the employees can be improved.

Some consideration can be done on legal matter: the impact on these aspects is mainly side effects of the exploitation of knowledge and information inside the companies. It was not in the focus of the project. The TexWIN system combines various data sources in companies and even adds new data. This aggregated data can then be used in various situations. One example would be to retrace production in case of warranty lawsuits. Another example would be to prove certain aspects of production to authorities.

Finally, we can take a more global point of view in this analysis: the impact on the market positioning is dependent on many variables but higher quality and reduced production costs strengthen the position of a company within the market. TexWIN can also support the exchange of information between partners of the supply chain. This improved communication supports the activities of all partners. The processes and planning of the partners can be better aligned leading to further cost reductions and better information exchange. For example the quality of a yarn didn’t meet the original product quality but can still be suitable for the production steps of the weaving company. The impact is depending on the quality of communication already established in the supply chain.

#### *7.1.1.2 Quantitative Improvement*

In 2010 the textile and clothing sector realized a total turnover of € 172 billion and employed 1.9 million people in more than 125,000 companies. More than 90% of the companies are SMEs. The industry exported products worth a total of € 34 billion. In the face of intense global competition European companies are increasingly turning to design and innovation to ensure sustainable competitiveness.

The textile industry is indeed becoming more and more an innovative sector. The European textile and clothing industry is a highly diversified, innovation and creativity driven industrial sector. A recent study showed that ca. 25% of the turnover stems from innovative products (less than 3 years old).

If we focus on the textile sector alone (i.e. the actual manufacturing of garments is excluded), we get the following data: employed 700 thousand persons and the value added generated by the textiles manufacturing sector was EUR 20 000 million (2009). About 60.000 companies contribute to this. The activities in this area fall in four categories: preparation and spinning (ca 10%), weaving (ca 20%), finishing (ca 10%) and 'manufacture of other textiles'.

#### *7.1.1.3 Scenarios for TexWIN impact*

If we consider the TexWIN outcome, it is fair to state that it targets predominantly the companies in the spinning and weaving groups, or about 30% of the numbers stated above. Further, given the consortium partnership, we focus on the data for these areas of two countries: Italy and Germany. An overview is given in the following table.

**Table 2: Estimation of some key figures for the spinning and weaving industry**

| | EU27 | Italy (40%) | Germany (15%) |
|---|---|---|---|
| # of companies | 18.000 | 7.200 | 2.700 |
| Turnover (M€) | 21.000 | 8.400 | 3.150 |
| Added value (M€) | 6.000 | 2.400 | 900 |
| # of people | 210.000 | 84.000 | 31.500 |

Based on these estimates, we can assume that, in totally, within Italy and Germany the results are potentially beneficial for almost 10.000 companies, generating together over 11.000 M€ or ca 1.1M€ per company, which indicates that the companies are (very) small.

To estimate the impact we take two scenarios.

- Scenario A. TexWIN system being brought to the market only via project partner DOMINA. Domina has currently 60 installations in leading firms. We estimate that within three years after TexWIN 2/3 of these installations will benefit. This can be realised via software updates. We only take 2/3 as some clients do not further evolve their system. So, the TexWIN results can in this way reach 40 companies. We further assume that the companies interested in our system are well above average in size, eg a turnover of 5M€, meaning we reach ca 200M€. For estimating a value of total impact in this group, we take a more positive scenario (25% increase – example of PIACENZA) and a more moderate one (6% time gain at Milliken). In the latter case, we can reach an annual impact of TexWIN of 12M€, in the former case about 50M€ from three years after project end.
- Scenario B. TexWIN reaches 2% of potential companies in Italy and Germany. More optimistic is that the developments from within TexWIN will find a more general entry in the market. We assume 2% (i.e. 200 companies) and assume that it will not be the smaller companies that will do so but the larger ones (estimated average turnover per company 10M€). Logically, the time to reach

this will be larger as in previous scenario, we assume 5 years. In this case, for Italy and Germany, we can reach a total turnover of 2.000M€ turnover. If we assume a productivity increase of 10%, it means that TexWIN can have an impact of 200M€ per year from five years after its end on. An increase of productivity of 10% or more is not unrealistic given that the productivity in the textile sector is currently much lower than the average in the manufacturing sectors.

The two scenarios above might seem daring but they are in our view still rather conservative.

- For scenario A we rely only on the impact reached by partner DOMINA, in scenario B we limit ourselves to Germany and Italy. Clearly, commercial partners potentially interested in the exploitation of the TexWIN results will also target other regions where introduction of the project results can also have a large impact, e.g. Spain, Portugal and France.
- Further, in the above scenario we only concentrated on two subsectors ('spinning' and 'weaving') and not on the subsector 'finishing'. Also for such activities, the TexWIN results can have an impact. However, given the wide scope of different processes that fall within this category, we did not include them explicitly. Nevertheless, it is important to point out that if this subsector would be added, we can add ca. 30% to the estimated impact, i.e. up to 70M€ extra (for scenario 2).

#### *7.1.1.4 General improvement of productivity in the textile sector*

Currently, the textile sector is quite weak when it comes to the productivity (expressed per person employed per year). Data from Eurostat show that the productivity in the manufacturing sector in general is 46k€ per person employed per year. The textile sector is well below: on average it is 29k€ per person per year, for the spinning subsector it is only 23k€.

One can wonder about the origins of this but it seems logical to assume that the lack of use of latest developments in software for production optimisation and tracking of production settings, production lots etc. are part of the cause. Indeed, introduction of automation, as for example in the case of partner BOTTO, will undoubtedly have a positive impact on the productivity.

#### *7.1.1.5 Coping with a changed labour force and novel client demands*

The developments in TexWIN can help the textile companies to two challenges they are currently confronted with: a changed labour force and novel client demands.

**Changed labour force**: In the past, it was not uncommon for a textile worker to start his career in a certain company and work there till retirement. This meant that for the company it was possible to gradually (over several years) introduce the workers to all aspects of the production process and to rely on them to have expert knowledge for the machine settings. Currently, this situation holds no longer. Blue collar workers often change their work, voluntarily or involuntarily. As a consequence, the knowledge should be kept external in a database-like structure and be easily available for the workers. Or, even better, the system should by itself know the required settings, switches to be made. The developments within TexWIN clearly contribute to this.

**Novel client demands:** Textile companies in the spinning and weaving business were used to work with large quantities. Their clients bought large amounts of certain products because the whole value chain was based ‘on stock’. This has radically changed the last years. More and more, downstream of the textile chain there is a request for personalised products. This does not necessarily mean personalised per person but per client. An example: for workwear it is no longer only the logo of the company that changes but the whole set of garments become individualised for that company (design, materials used, colour…). As a consequence, the size of the production orders is reduced drastically. This has several consequences, in the areas of the actual manufacturing but also for the logistics. In both cases, TexWIN results can help a lot: easier switch of machine settings, less down-time, immediate availability of production data in electronic form.

### 7.1.2 Impact on the Plastics converting sector

This chapter will give a more general analysis of the impact of the TexWIN project results on the European plastics converting sector. In the first section, a more qualitative approach is taken, while in the second section, we will try to give a more quantitative impact, based on available market potential.

#### *7.1.2.1 Qualitative Analysis*

The TexWIN system focuses on the gathering and storage of essential information related to machine settings and process parameters needed to produce a certain product in the most efficient way and assuring the best possible quality. Based on CBR algorithms, these settings and parameters can be derived by combining and evaluating process state information as well as product and material properties.

In the plastics converting industry, a large part of the down time of machines (in some cases up to 30% of total down time) can be assigned to mold and color changes (set-up times). These set-up times can be divided in so-called “external” and “internal” set-up time. “External” set-up times can be carried out upfront by the set-up crew provided that they are informed in time about the upcoming changes. This is typically the task of a well-designed MES system. “Internal” set-up times include all the tasks needed to start the production with the new tool or color/material combination: mounting the tool, loading the new material/color combination and fine tuning the machine control unit to find the optimum settings and parameters.

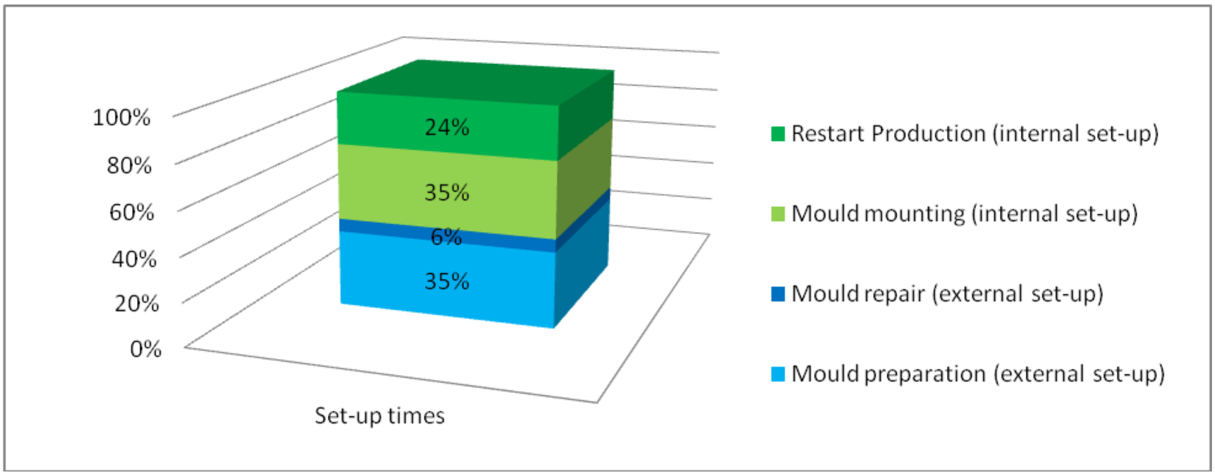



**Figure 27: Composition of set-up times (average for injection molding)**

If all the information regarding machine settings are available for each product to be produced, the “trial and error” sessions when switching from one product to the other, can be eliminated. As the “restart production” typically accounts for 25% of the total down time for set-up, this means that indeed a system as developed within TexWIN can result in a 25% reduction of total set-up time. Taking into account that on average about 4% of the total available production time is lost due to “changes” and set-up, this means that an overall 1% efficiency increase can be obtained, meaning 1% more production output with the same number of machines.

A second benefit is related to the production of scrap during machine set-up. While changing from one product to the other on the production machines, be it by changing the tool or by changing material/color, there is always a certain amount of products produced while fine tuning the machine. These products are in most of the cases not conforming to quality standards and are rejected. By getting the settings first time right, this scrap production can be seriously reduced, again resulting in additional saving in raw material. It is estimated that about 1% of production output is lost due to “start up scrap”. Eliminating this start up scrap, results in another 1% productivity improvement.

To summarize, one can state that at least 2% productivity improvement can be reached when implementing the TexWIN concepts in plastics converting plants.

Having a central storage of the machine settings for each product also assures that always the same settings are used to produce a certain product. This results in a stable quality level throughout the plant. Machine settings are becoming independent of the operators, thus eliminating the “human error” factor.

Of course, also in the plastics industry, TexWIN can have a large impact on the “knowledge management” within the company. A lot of knowledge is available with the operators and machine setters. If one of them leaves the company, sometimes valuable knowledge is lost, again resulting in organizational problems, decrease of quality and efficiency.

In case new products are developed, the knowledge already available in the data base about similar products, can be used to fasten shorten developments times.

#### *7.1.2.2 Quantitative Analysis*

The plastics converting sector in Europe generates a turnover of approximately 280 billion EUR per year (2010 figures) and employs roughly 1.4 million people.

The industry is contributing considerably to the health and welfare of the EU population and offers a dynamic environment for 50.000 small and medium sized companies (average number of employees per company is 25). The industry exports products worth a total of 25 billion EUR.

Packaging is the most important end market for the goods produced by the plastics converting sector (38%) followed by the building & construction sector (21%). Automotive counts for 6% of the total output of the sector.

In order to compete with imports of low cost countries, European plastics converting companies have to focus on efficiency, quality and flexibility. This is exactly where the concepts developed within TexWIN can help the companies in achieving their goals.

#### *7.1.2.3 Scenario’s for TexWIN impact*

From the below chart, it shows that Europe counts for 28% of the world total output of plastics products.

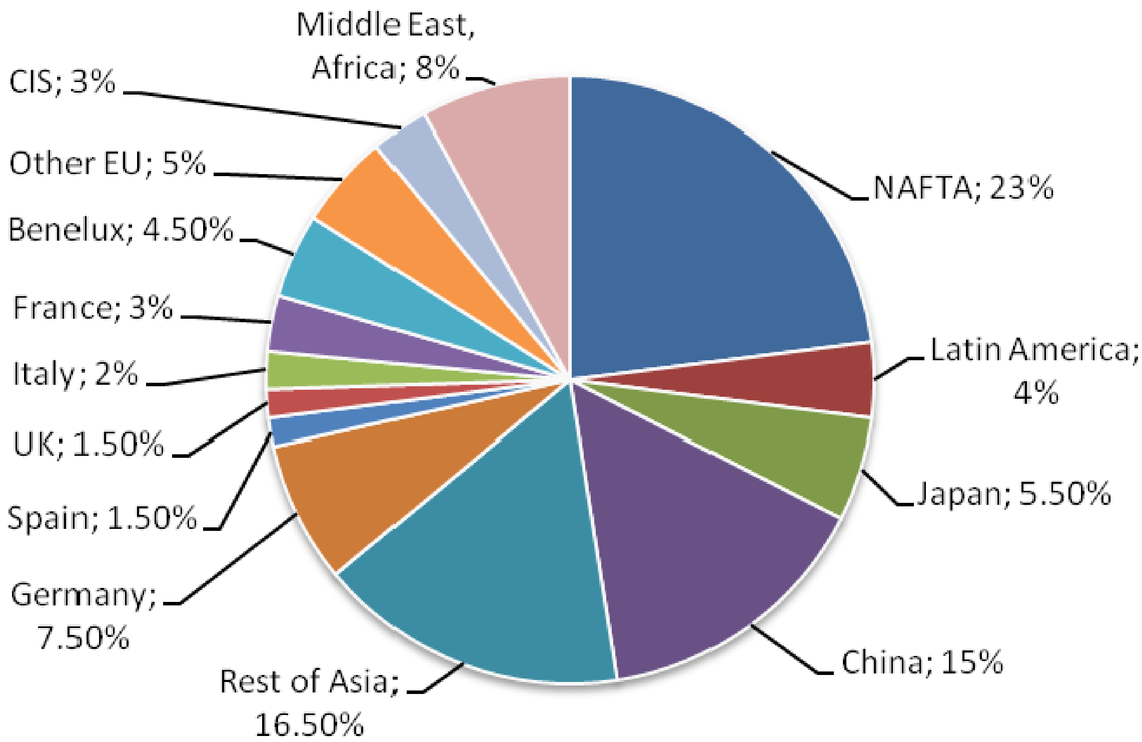



**Figure 28: In order to estimate the potential impact of TexWIN, we take two scenarios:**

- Scenario 1: TexWIN brought to market by project partner BMS. BMS has about 400 MES installations in European plastic converting companies. We estimate that within 5 years after completion of the TexWIN project, about 50% of these companies (the larger ones), or 200 companies can benefit from the introduction of the TexWIN concept. With an average yearly sales figure of 25 Mio EUR per company, the target is a 5 Billion EUR output or 1 Billion EUR output per year. With an estimated 2% efficiency increase, this means a 20 Million EUR additional output per year with same number of machines and employees.
- Scenario 2: TexWIN reaches 1% of all companies in Europe Under the assumption that not only BMS will bring the concept to market, but that the TexWIN approach reaches the market through more general channels, one can estimate that about 1% of the total companies will be reached, or about a 30 Billion EUR sales volume. The time to reach this target might be longer, for example 10 years after completion of the project. The same reasoning of 2% increase in output would result in a 600 Million additional output per year with same equipment and personnel.

### 7.1.3 Potential TexWIN impact on other sectors

In generic terms, we can summarize the main TexWIN results as follows:

- Improved knowledge management: no loss of the knowledge gained in the enterprise, and its better organisation using TexWIN and its software integration in factory
- Production process optimisation, both in term of machines to use and their scheduling

- Machine functioning utilisation: in cases where a complex set of parameters is required as machine settings, TexWIN can potentially impact the efficiency by reaching the optimised settings much faster.

Clearly, these results are not only for the textile industry interesting but also in other domains that struggle with similar challenges as the textile sector and have a similar background, i.e. (very) small companies in the manufacturing sector that have to deal with a wide variety of products that require adapted machine settings or process recipes. We consider some examples.

One example is the group of SMEs of the European *furniture sector*. The European furniture sector comprises around 150,000 companies, 86% of which are micro enterprises (less than 10 workers). The sector generates a turnover of almost €126 billion and an added value of €38 billion and employs around 1.4 million people (EU27, data from 2006).

Further interesting sectors are the *leather tanning industry* (€10.6 billion in turnover – 3.700 enterprises – 52.000 people) and the *footwear industry* (€26.2 billion in turnover – 26.600 enterprises – 388.000 people) which are also characterised by small companies and a large variety of products[Fehler! Textmarke nicht definiert.].

As an example, we mention that in the footwear industry the companies remaining in Europe cannot compete with price. So, they need to compete via other channels, for example by offering high added value products or by supplying their customers with dedicated series, e.g. individual size, shape, fashion and orthopaedic requirements. Another option is to offer increased production flexibility. Another aspect is the fact that also furniture objects are subject to faster changing fashion cycles. Clearly, all these pose a serious challenge when it comes to the knowledge management within the small, or often even micro, companies. Here, similar as for the textile sector (case at terry cloth producer Dyckhoff), the TexWIN developments can have a positive impact.

Another example relates to the furniture industry. In 2011 the project COLORMATCH (Development of an expert system for the colorant formulation in the dyeing process of veneer in furniture industry) was finalised. The project aimed at developing an expert system based on computer vision which would be applied in furniture factories and automatically collect and interpret data to identify and define the adequate colorant formulation for achieving a target colour. One of the goals of that project was to reduce the formulation time significantly. This shows the relevance of such kind of problems in the industries and how TexWIN (for example for the Milliken test case) can be very interesting for the furniture industry.

### 7.1.4 Dissemination Events

#### *7.1.4.1 PO.IN.TEX - INNOVATION DAY*

The most important dissemination event in TEXWIN project in the last year is represented on INNOVATION DAY, in Biella, contemporary to final meeting review. Born in 2009, Po.in.tex – Polo di Innovazione Tessile (Textile Innovation Cluster), is an association of businesses (micro, small, medium and large), consortia and research organizations whose purpose is to promote industrial competitiveness through the cooperative innovation. PO.IN.TEX aim is to activate a systematic process of reconcile between supply and demand of innovation, which starts from real requirements of firms and involves several actors of the textile chain finding channels, languages and projects into which producing a competence growth and added value for firms. Main activities are: audit and recognitions of the requirements of companies, networking, partner search, internationalization, Innovation Days.

“Innovation Days” are periodical events organized from PO.IN.TEX. on specific matters in order to disseminate information and new about innovation. Innovation Day is a workshop where:

- audience are Textile industries
- speakers are organizations that have some interesting info to share with the audience.

The INNOVATION DAY of 12$^{th}$ March 2013 was totally dedicated to TEXWIN project dissemination.

#### 7.1.4.2 Other Workshops

PIACENZA, UPC, DOMINA presented in different context the TEXWIN project. DOMINA presented to a closed industrial cluster TEXWIN actual achieved objectives. This industrial cluster represent a potentially customer (6 spinning mill). The event has been hold at Biella Industrial Union. PIACENZA, DOMINA and UPC participated at different workshops focus on EU research activities promotion meeting. Audience was represented from researchers and industrial partners.

#### 7.1.4.3 Yarn exhibition

One exhibitions (October 2012) in Milano were significant occasions to introduce the project to people concerned by fabrics production and uses. FILO has been attended by Marchi: during this international yarn exhibition, ~70 European yarn producers received the visit of ~1000 customers coming from all-over the world.

#### 7.1.4.4 Fabric exhibition

2 trade fairs (May 2012 - January 2013), held in Frankfurt were significant occasions for German industrial partner to introduce the project to people of textile sector. In the same time, italian industrial partners participated at 2 important fairs, held in Milano and Paris (“Milano Unica”, “PREMIERE VISION”). During these international fabric exhibitions, ~150 European weaving mill producers receive the visit of ~1500 customers coming from all-over the world. These opportunities were significant occasions to introduce the project to people of textile sector

#### 7.1.4.5 Plastic exhibition

One exhibition (FAKUMA - October 2012) in Friedrichshafen was significant occasions to introduce the project to people concerned by plastics sector. FAKUMA has been attended by BMS: during this international plastic process exhibition, ~1700 Exhibitors from 120 countries received the visit of ~45000 customers coming from all-over the world. These opportunities were significant occasions to introduce the project to people of plastic sector.

#### 7.1.4.6 Other exhibitions

We also took part in other dissemination activities during particular exhibitions not strictly connected with industrial partners. In that case focus of dissemination was general oriented to academic information.

#### 7.1.4.7 *Publications*

A short article presenting the TexWIN project has been published in the magazine "Biella Style", associated to a publication of DOMINA. "Biella Style" is a monthly magazine with big diffusion in Biella area. Centexbel wrote an article in the periodical newsletter published form the institute about TexWIN.

#### 7.1.4.8 *Others*

Other dissemination activities like presentation of results to entrepreneurs, stakeholders and students have been taken place.

### 7.1.5 Exploitation

The TexWIN project produced a wide variety of exploitable results. Some are of commercial interest where others are important for scientific use. Following is an overview of the identified exploitable results.

- Specifications of the TexWIN-Concept for factory control
- Methodology for applying the TexWIN concept
- Case Adaptation Methodology
- Case Structures
- Factory Ontology
- Factory Model
- Production unit controller
- Automatic CBR system
- Factory Controller
- Communication framework
- Software interfaces to enterprise software
- The complete TexWIN-system (factory controller, production unit controller, communication framework)
- Pilot system of the TexWIN
- Standards for factory communication in textiles and plastics
- Application guidelines and templates for industries
- Academic description/courses

The commercial exploitation of the following four results has been started already by the partner BMS, Domina and UPC.

#### 7.1.5.1 *Similarity Algorithms*

A procedure for assessing and computing the similarity degree of two yarns in the textile industry context will be patented. This procedure is a key factor for predicting the new settings of a textile machine for producing a new yarn (spinning machine), for producing a new textile fabric (weaving machine), etc. Thus, it is useful for several textile machines.

#### 7.1.5.2 Integration of TexWIN in system Domina Dot.PLAN

TexWIN currently gives basic suggestions about how to perform a better production scheduling, without doing it automatically. TexWIN base these hints on a production monitoring system, essential element to integrate it within Domina's Dot.PLAN. In fact, Offline and Online Optimizers work at a process level (embracing several phases) giving the possibility to optimize by keeping balanced the buffer level (the pre-production row: that real or dummy warehouse where products are accumulated before being worked). Moreover, in order to have an estimation of the filling rhythm of these buffers, TexWIN relies on PUCs, working on CBR system.

#### 7.1.5.3 TexWIN Interfaces to industrial PDAs

DOMINA developed TexWIN interfaces for industrial PDAs. These interfaces are web oriented, and work on web services in SOA architecture. Through this interface it is possible to insert into the system some data currently not taken into account by various MES at machine level. Nevertheless some data (for example quality data, as demonstrated by the Botto's use cases) are very important for a holistic management of the production. Domina will sell the hardware (PDA) including interfacing the system for inserting these data. The integration with TexWIN will be an added value, and this market approach could pave the way to advise customers of this possibility.

#### 7.1.5.4 Integration of TexWIN components in BMS's suite of MES applications

**Textiles: weaving and knitting**

From the TexWIN pilots, the use cases for weaving at Botto and Dyckhof give the best match with the typical functionality of BMS's MES solution for weaving and knitting. In the Botto use case, TexWIN exploits the data from a weaving machine monitoring system and from quality data of fabric inspection. In fact both sources are covered by specific BMS software modules.

- WeaveMaster monitors and synchronizes all manufacturing and logistic activities within the weaving mill, from yarn purchasing and inventory up to the shipment of the finished fabric. The core resides in an automatic data-collection network at the machines, which allows the WeaveMaster users being constantly informed about the actual situation on the production floor.
- QualiMaster offers a powerful fabric inspection solution covering the 3 area's: on-loom during manufacturing, grey inspection immediately after weaving and finished fabric inspection on the end product. The main aim is to reduce off-quality by immediate feedback to production and allow full analysis of quality and defects.
- Also Cyclops, which is BMS's new automatic on-loom fabric inspection system, fits in this architecture. Cyclops detects warp, filling and point defects during production by means of a moving camera system installed on the off-loom take up. In case of a warp defect or a concentration of filling or point defects, the system stops the loom, lights a warning lamp in the loom's light tree and informs the defect nature and location on the loom's microprocessor display. The system holds the loom in the stopped position till the weaver has made the “defect corrected” declaration.

In a typical configuration for weaving, TexWIN receives from MES: the actual planning of production orders and raw materials (=warps and weft yarn); the manufacturing performances e.g. machine speeds, efficiencies, the warp and weft yarn breakages; the fabric quality, e.g. classification and defects including type, severity and location. In closed-loop TexWIN can provide feedback with suggestions. Botto manufactures short pieces, which allows awaiting the completion of the first piece of an order: the feedback from TexWIN will still be in time for the remainder of the job. Unfortunately pieces are often much longer, which reduces the relevance of the feedback from grey inspection. In such case on-loom fabric inspection and more specifically the Cyclops automated inspection can address this problem: QualiMaster will forward quality data to TexWIN, while the order is still on the machine.

**Plastics: injection-molding and extrusion**

Europe has a thriving industry of plastic converting. Fortunately the plastics industry suffered less of the current push to move production eastwards. This is caused by the fact that plastics are typically lightweight but voluminous products which are not easily transported over long distances. The extreme are pipes and containers, which in proportion of volume are 95% of empty space. As such the distance between manufacturer and user cannot be more than a couple of hundred kilometres. Still the industry feels the same push to improve productivity and quality. Here TexWIN will be offered as add-on to BMS’s MES application for plastics, PlantMaster. PlantMaster monitors and synchronizes manufacturing activities from independent operations to globally distributed plants.

TexWIN will support the selection of the best settings in order to decrease downtime and scrap production due to set-up, and in general to aim for settings with better productivity, quality and energy performance. Modern machine controllers already give assistance to find good initial settings, but this is based rather on heuristics. In contrast TexWIN in combination with PlantMaster has a much more complete picture, both actual and historical, including data about the machine, the mold, the used and/or available peripherals and info about the raw material lots.

# 8 Public website address and contact details

**Public Website**

http://www.texwin.eu

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