Public Final Report of EUTIST-IMV Activity OPTAMS – Optimiser All Monitoring System

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Abstract
Manufacturing industries integrate different resources in their production pipelines: material, personnel, machine tools, robots, etc. The resource management has to optimize production costs by taking into account on-line changes. The purpose of OPTAMS (Optimized All Monitor System) is to integrate an on-line optimization tool with a resource management system and a control system. OPTAMS can directly control machines and personnel. OPTAMS allows to monitor the production process in order to run the re-optimization, if the preceding planning has to be retuned or updated. For example, for contingency changes on the resource conditions, new orders, etc. Thanks to the optimization, the company is able to increase the production efficiency. OPTAMS can control flexible productions, adapt the production to the available resources. The optimization is based on Taboo search and the functional consists in several terms allowing finding a compromise from optimizing, costs, resource distribution workload, time to delivering, delay, etc. The whole system's architecture is based on a distributed control system which integrates CANbus and Ethernet devices. OPTAMS has been realized as an European Commission R&D IST project, and has been validated at SHELBOX factory; the company produces mobile houses and a relevant increment of production efficiency has been obtained.

Keywords: Database, Information Technology, Industrial Engineering, Manufactoring Techniquis Artificial Intelligence, Optimization Tabu Search, Scheduling, Job Shop

Synopsis
The production time is one of the most important factors of the product costs. It is also a variable that**,** unlike the availability of materials**,** depends on the organizational ability of the enterprise and on a correct management of personnel, of tools, and machinery, etc.
The main purpose of a resource manager system is to determine a precise estimation of certain production costs for each single product by means of the management of all the production resources**,** like human resources, machines and materials in the different production phases. In addition, the monitoring of production data related to the personnel, the machines, and the material resources permits a more effective integration and management of the production process. In some cases, the integration may involve the production of Analysis and Reporting and even a more precise and effective planning of orders, thus allowing the reducing of the storage. Through the integrating of resource manager system and on-line optimization technique is possible to increase the production efficiency.

The optimization process regards the following problem: the firm receives several orders from its clients. Each order might consist of one or more jobs (articles to manufacture). Usually one job must be delivered within a fixed date (deadline). This parameter imposes constraints on the scheduling algorithm. Every job is liable to different operations (tasks) and each task must be carried out in the right order. The entire cycle of the production consists of the several production phases, each corresponding to one or more resources which can perform the

related operation: a phase, for instance, could be performed on different machines or by different people. This could happen likewise for the other types of operation. Some constraints need to be considered with regard to the priority of the phases.
The aim is to plan the production, minimizing the throughput time, respecting the fixed delivery deadlines, minimizing the costs of production and minimizing the single resources activity fragmentation. An extreme flexibility is required, because either malfunctions or wrong procedures are rather frequent in a plant of such complexity. Therefore it must be possible to re-plan the process at any time to take into account possible differences from what has been planned.

To cope with the above problems we have realized OPTAMS solutions and architecture. OPTAMS is an on-line optimization tool integrated with a resource management system, called AMS (All Monitoring System). OPTAMS is an on-line optimization tool that permits the monitoring and the management of production process, controlling all kind of resources. Every change in resource condition may be programmed to start a re-optimization of the whole production.
An OPTAMS complete architecture is comprised of two main software component: Optimizer and Process Manager AMS. The Optimizer implements the on-line optimizer/re-optimizer taking into account the available resources and their status. This component implements a specific optimization based on TABU search. Tabu Search optimization algorithm was invented by Fred Glover in 1986, and has been refined and tuned in the project. This iterative algorithm explores some possible solutions of the problem (configuration of the plan) making repeated moves from a solution to another. The next solution is individuated by the group of solutions, called candidate solutions, that can be reached from the previous configuration executing a “move” (for example: exchange of two or more operations assigned to the same machine, making permutations, etc.). The main characteristic of the Tabu Search is the introduction of the concept of memory in the search process of the better solution. The memory consists of a list of moves, called *Tabu list*, that cannot be executed at the current iteration to move towards the next solution. The moves belonging to the Tabu list are moves performed recently or that were performed frequently in the last iterations. The memory structure impedes to the algorithm to remain trapped in early local minimums, leading it to the space of solutions still unexplored, permitting the performing of moves characterized by values of the cost functional major than that of the current solution. The Tabu state of a move can be changed to an allowed state if the value of the cost functional associated with it is the minimum between all determined until the current solution (standard criteria). The procedure stops when a fixed number of iterations have been performed or when the process is not capable to improve the solution after a defined number of iterations (this means that a quite stable solution has been obtained and it is very difficult to reach a better solution, if any). The Tabu Search has been selected to solve the scheduling problem of OPTAMS. The advantages in a comparison with other techniques (such as Genetic Algorithms) are robustness and the rapidity.
The Process Manager AMS attempts to manage the production according to the planned activities defined by the Optimizer. It is able to take into account of the actual values measured on the production process, through the time, such as changes in starting and ending time, respect the planned. When critical changes and variations are recorded**,** then a re-optimization phase is needed. Planned and real measures are used by the Optimizer to perform or not a re-optimization on the basis on selectable criteria.

OPTAMS impacts on the management of the production budgets and increase general production efficiency. By means of the optimization, the company is able to reduce and control the maximum workloads permitted by the structure. Consequently it is possible to decide if there is the need to hire other personnel in order to satisfy the new requirements**,** avoiding to turn to extraordinary work that has a higher cost and does not help the increment of occupation.
OPTAMS has the capability of controlling flexible productions**,** adapting the production to the available resources in quasi real-time. OPTAMS presents a cost very low solution with respect to well-know commercial products for the production control. Moreover, OPTAMS is effective and precise in controlling human resources and machine tools with respect to other products.

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Executive Summary

The purpose of OPTAMS (OPTimised All Monitor System) is to propose an on-line optimization tool with an integrated resource management system, called AMS (All Monitor System). OPTAMS is directly capable controlling machines and personnel. This solves production process problems for those companies that have a strongly differentiated and flexible production such as many manufacturing SME.
On-line optimization tool contrary to other ERP (Enterprise Resource Planning) products which are typically off-line since they are tools for planning a stable (a-regime) production (production presenting repetitive activities over several months). OPTAMS permits the monitoring of production process in order to run the re-optimization if the precedent planning cannot be executed (or it is not any more efficient for the resource exploitation) for various reasons, for example, changes in the conditions of the resources capable to execute the production, arrival of new orders, cancellation of orders, etc.
The factory LAN connects the OPTAMS Server, where reside the activities database, the Administrative Server and the Process Manager with all the terminals in the plant. There exist MICROTERM terminals and a set of sensors and interfaces towards Machine Tools and Robots: these terminals are the data acquisition points for the information data on the production evolution. Typically, there is a terminal close to each machine tool for the personnel, while the number of MICROTERM terminals used for managing the free

manufacturing parts depends on the size and on the type of the plant. The machines are directly connected to the system via CANbus technology, according to the MUPAAC architecture on which the OPTAMS hardware and network is based.

OPTAMS impacts on the management of the production budgets. OPTAMS has the capability of controlling flexible productions**,** adapting the production to the available resources in quasi real-time. It has a very low cost with respect to well-known commercial products for the production control and at the same time it is much more effective in controlling human resources and machine tools, respect to other products.

The time of the resources is one of the most important aspects in the estimation of the production costs in manufacturing SMEs. It is also a variable that**,** unlike the availability of materials**,** depends on the organizational capability of the enterprise and on a correct management of the personnel, of tools, etc. The main purpose of a resource manager system is to determine a precise estimation of production costs for each single product by means of the management of all the production resources**,** like human resources, machines and materials in the different phases of production. In addition, the insertion of the acquisition system of production data permits to obtain in real time: the data related to the personnel, the collection of machines' data, the advancement of the production, the valorisation of the production, the presence of a bi-directional messages Production Office system - Commitment/phase/operator for the integration of the quality system and the Analysis and Reporting. Through the integrating of resource manager system and on-line optimization technique is possible to reduce the costs of the production with respect to those obtained by a manual planning of the activities.

The optimization process regards the following problem: the firm receives several orders from its clients. Each order might consist of one or more jobs (articles to manufacture). Usually one job must be delivered within a fixed date (deadline). This parameter imposes constraints on the scheduling algorithm. Every job is liable to different operations (tasks) and each task must be carried out in the right order. The entire cycle of the production consists of the several production phases, each corresponding to one or more resources which can perform the related operation: a phase, for instance, could be performed on different machines or by different people. This could happen likewise for the other types of operation. Some constraints need to be considered with regard to the priority of the phases. The aim is to plan the production, minimizing the production time, respecting the fixed delivery deadlines, minimizing the costs of production and the resources activity fragmentation, etc., according to the needs and strategies of the SME. An extreme flexibility is required, because either malfunctions or wrong procedures are rather frequent in a plant of such complexity. Therefore it must be possible to re-plan the process at any time to take into account possible differences from what has been planned.

The user interface of OPTAMS allows the selection of the orders to be involved in the production planning. The result obtained by the optimization process (the production plan and the main figures of the results: functional value, value of the terms of the functional, last deadline, efficiency, etc.) are visualized at the end of the process or when needed. In addition, a numerical comparison of the planned against the effective is performed to give objective figures about the production process. For example, the estimation of the maximum deadline,

the estimation of the mean deadline, the number of non started activities in time with respect to the total number, the number of activities finished in time with respect to the total number, the efficiency of the plan (the ratio between the number of available hours of resources with respect to the worked hours or with respect to the planned to work hours, etc.).
The OPTAMS solution has been validated in the SHELBOX plant. SHELBOX is a factory producing mobile houses. The validation consisted of the loading of their orders into the OPTAMS system and production of an optimized planning for a real working period. Then the planned schedule has been used to manage and control the production process. This experimental activity has demonstrated the increment of efficiency that can be obtained with the usage of OPTAMS with respect to manual planning and with respect to any plan based on deadline monotonic or priority based allocation. In addition, the optimisation has found a compromise from reducing the production time and costs.

Full Technical Text

State of the art

The job shop problem can be regarded as a global model for organizing the activities of production systems. In the model each job is characterized by a technological cycle that needs the intervention of several different resources. The order in which the operations on the resources have to be performed varies from a job to another and the resource on which each operation must be realized is previously assigned. The resources are identified as classes of resources instead to be namely identified. In current industrial reality, characterized by systems with a big number of resources and final products (and consequently a big number of variables involved), the problem of the production "scheduling" or optimization is really complex (NP-hard). The use of a computerized support is, in these cases, an essential tool both for the solution of the scheduling problem and for the related optimization.

There are four reference areas for technologies aiming at any control and supervision of the different levels of organization within a company:

- ERP (Enterprise Resource Planning) – is the highest planning level and includes the whole company resources, starting from the unified management of the information among different branches of the same factory up to the management of the work assignment and planning for the personnel with functions as production previsions, commitments, etc.
- MRP (Manufacturing Resource Planning) – is the level having as a task that of managing and planning the production; the modules which belong to this level are strictly connected to the functionality of the company managing system.
- MES (Manufacturing Execution System) – is the level that interfaces and connects the planning with the control level in order to make executive the production plan, monitoring people and resource consumption.
- Control level (PLC, DCS) – is the level controlling the field devices and interacting with the operators for realizing the production.

Recently, new optimization techniques have been invented in order to reduce the time to produce suitable solutions. These are typically sub-optimal but they are capable of producing reasonable solutions in a very short time of computation. These innovations have permitted big improvements in planning and optimizing the production process. They permitted the management of problems that before could not be considered as the flexible job shop problem or the resource constrained project scheduling. Some examples of the innovative algorithms recently developed include the simulated annealing, the taboo search, the genetic algorithms, and the genetic local search. The strategies that are adopted by these techniques are called local research techniques. They allow piloting a short-sightedness algorithm toward the optimization, accepting also behaviors that do not improve the current solution. The first two are substantially short-sightedness heuristic techniques, that is, based on the assessment of solutions in the immediately closeness of the solution at the current iteration; whereas the third uses a particular philosophy derived from mechanisms of biological reproduction and selection that are difficult to be placed in a classical scheme of classification of the heuristic procedures. The last technique mentioned is an improvement of the genetic algorithms regarding the quality of the solution.

The planner performs the task of optimization of the phases of the jobs taking into account all the constraints that are present (in the rest of the document the terms "job" and "operation" can be used with the same meaning of phase, sub-job, in general). When a plan is ready, it presents the results as a list in which all phases that have to be performed are contained; the so-called schedule. The optimization is given from the order in which the different phases appear in the list: the first phase will be used as first, the second as second and so on. In effect the phases may present relationships of presence and in some cases, very different and non - linear dependencies may be defined. The optimizer must manage the traffic of files and pieces that is generated by analyzing the phases as they present in the list and sorting them coherently with the chosen management policies.

Manufacturing industries integrate in their production pipelines different resources: material, personnel, machines tools, robots, etc. The resource management has to be effective to have market competitive costs. For this, off-line resource planning tools are typically used. Most of them are capable to plan and optimize the production of stable production pipelines (the same set of products for several months). When the production is strongly differentiated these tools are unsuitable.
The production of SHELBOX is characterized by several delays and pauses for personnel and machines. Several different parts are produced in the production environment by the same personnel and machines, to satisfy the request of personalization of the provision of the caravans, motor-homes, mobile homes, etc. To this end, it is very important to perform optimization and on-line re-optimization, and to have the possibility to communicate the work to do to the personnel at the right time and via terminals. This allows changing the production order dynamically**,** according to the re-optimization and thus the dynamic condition of the production. This is presently left to the sensitiveness of the production responsible but the complexity of production is so huge and complex in terms of constraints among phases that several delays, pauses, etc., are inevitably produced in their model of production.

To solve these problems**, an on-line optimizer integrated with the resource manager is needed** such that included in OPTAMS. OPTAMS integrates an on-line optimization technique of DSI partner with the on-line distributed resource manager of SED partner called AMS (All Monitor System). OPTAMS is based on barcode pens, micro-terminals and identification keys for managing peoples and CANbus for managing machines. OPTAMS is collocated among the MRP, MES areas and the level of control related to the needs of the factories that present differentiated productions with the necessity of frequent re-optimizations.

The peculiarity of OPTAMS is in the total automation of the MES and control levels, including some aspects MRP that are functional for the management of production in an automatic manner. Typically, the MES solutions collect data coming from the field devices and verify their congruence with the adopted planning, dynamically modifying, if necessary, the production plan. From the literature and the market analysis, it has been observed that many other systems cannot order the execution of the different working phases because this task is generally manual or made through paper. In those cases, the operator has a print-out of the production program generated by the planner. Moreover the planning products are not sufficiently flexible to be capable of considering all the constraints used for the direct control of the different resources: precedence, type of machine, groups of operators, competence of personnel, etc.

The main innovations of OPTAMS consist of the integration of the AMS resource manager with the on-line optimizer built, at the state-of-the-art, by DSI. The on-line optimizer is based on Taboo Search.

In order to obtain an effective reduction of production costs from the information flow about measurements of times, it is necessary to use this information to plan the future production to appropriately organize the sequence of the different operations. For example, the transferring of files, the movement of raw pieces, the beginning of the workings, the activation of personnel, etc. This task is performed by a planning algorithm that optimizes such sequences taking into account the different needs (delivery times, availability of resources, errors, variance of workload among resources, general reduction of delivering time, reduction of production costs, exploitation of resources, etc.). If the production process presents a considerable number of manufactures and/or the number of different products passing on the same production line is big, then the necessity of an automatic on-line optimization planner of the production is indispensable to produce the product at competitive costs and prices.
The phases of resource management and optimization planning are related by some constraints of precedence, and in some cases they are independent each other. This means that a good resource management of the production is impossible without a previous planning, nevertheless the management policies of the production pipeline are independent from the adopted planning model. The optimization engine has to be also capable of supporting the re-optimization when critical cases occur which invalidate or diverge from the planned schedule. For instance when the efficiency of the actual production decreases due to

- the lack of resources: human or material,
- the accumulation of delay,
- the presence of too large a variance of workload among resources,
- the manual request of machine to perform a correction,
- the breaking of a machine tool,
- the arrival of new urgent orders or the cancellation of running orders, etc.

In those cases, the manual re-optimization is possible but it is very hard to rearrange all changes in an optimised manner by continuing to maintain the current production that is running. This typically takes a very long time to be performed during the production produces. The action of optimization/re-optimization can be useful for assessing the impact of changes in the production process. These can be provoked by new products to be produced, new resources, changes in the current production (time, number of pieces, etc.), problems to people and machines, etc.

The control of the work of the personnel is performed by using the distributed system at the basis of AMS supporting the OPTAMS. This is endowed with industrial computers and microterminals that allow the personnel to read the actions to be performed and to record their work. This is possible by using bar code pens and special keys that allows the system to recognize the single person as belonging to a given category of working people in the factory. This allows controlling and tracking the production without tracking the single person, according to the legal rules.

Technical Approach

The following requirements are related to the production process and the optimization model for the production planning based on the enterprise process management tool, AMS.

The management strategy is the way the articles which are produced or assembled transit in the plant and the information that eventually accompany them, like the status evolution of the semi-manufactured and the raw materials in the production cycle. The total integration of the available resources is hardly reachable without a focussed management of information. The management strategy must address also this point. To make possible the management of such information flow it is necessary to organize the sequence of the various operations that have to be performed, like the transfer of information to machines and operators etc. This task must be addressed by a planning algorithm that optimizes activities by taking into account the various needs (deadlines, resources availability, delays and errors). An automatic planning with resource management optimization is especially needed when the number of resources is not low or when the number of articles to manufacture and their production phases and corresponding constraints are high. This is typically true when the process is fragmented in several phases and/or the production includes several different types of products.

It is important to point out that the production optimization and planning strategies are independent from the management strategies introduced before (way in which the articles produced or assembled transit in the plant). In fact management strategies are essentially related to the production phases adopted to realize the articles, while optimization strategies are essentially an operational research problem. There cannot be a good management of the resources in the plant if there are not available both strategies. The figure below illustrates the flow of data from the database orders to instructing the resources on the task to be performed during the production:

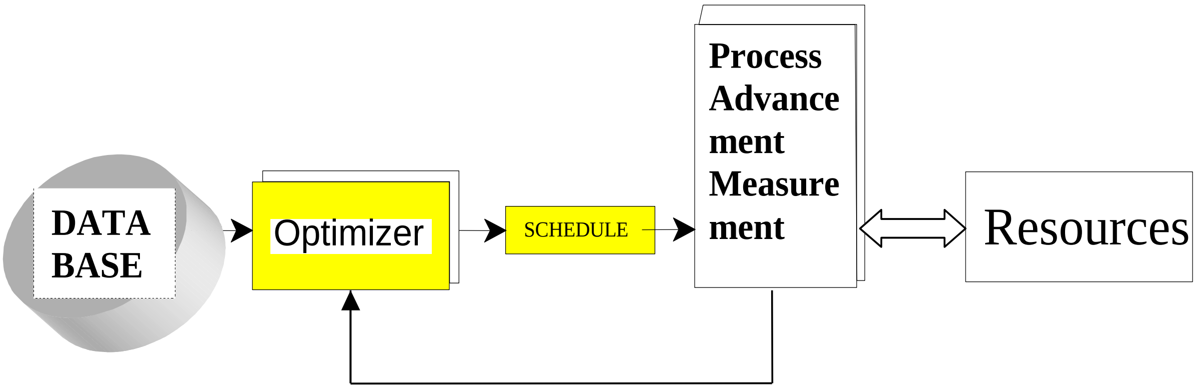

Fig.1 – The dataflow in OPTAMS, main components

The optimization module (see Fig.1), called Optimizer, receives as input various information on the enterprise orders inserted in the system AMS. The AMS system contains information that are used by the Optimizer module that consist essentially of:

- deadline of the order,
- creation of an enterprise order from the customer order,
- creation of the list of articles and semi-manufactured from the order,
- description of the articles that the plant can manufacture,
- production phases characteristic of the firm,
- description of the enterprise's resources.

The planner optimizes the assignment in time of the sub-work phases to the various resources of the plant in order to optimize the resources management. The assignment of the production phases (or tasks) to the resources must take into account all the constraints between the various production phases and the resources. The activity of the optimization module results in an optimized schedule containing all the phases that must be performed to respect the clients orders and the deadlines, the resources that must perform them (the kind of resource depends on the kind of activity of the plant) and the moment in which that resource must perform each production phase. The optimization results in the order of execution and resource mapping of the production phases in the schedule. The optimization module consists of operative research algorithms that try to find the best configuration to minimize some factors to produce the "best" compromise planning on the basis of the defined factors, for instance minimising deadline and costs, etc.

The planner performs the task of optimization of the phases of the jobs taking into account all the constraints that are present (in the rest of the document the terms "job" and "operation" can be used with the same meaning of phase, sub-job, in general). When a plan is ready, it presents the results as a list in which all phases that have to be performed are contained; the so-called schedule.

Manufacturing industries integrate in their production pipelines different resources: material, personnel, machines tools, robots, etc. The resource management has to be effective to have market competitive costs. For this, off-line resource planning tools are typically used. Most of them are capable to plan and optimize the production of stable production pipelines (the same set of products for several months). When the production is strongly differentiated these tools are unsuitable.

The production of SHELBOX is characterized by several delays and pauses for personnel and machines (see Figs.2, 3 and 4). Several different parts are produced in the production environment by the same personnel and machines, to satisfy the request of personalization of the provision of the caravans, motor-homes, mobile homes, etc. To this end, it is very important to perform optimization and on-line re-optimization, and to have the possibility to communicate the work to do to the personnel at the right time and via terminals. This allows changing the production order dynamically, according to the re-optimization and thus the dynamic condition of the production. This is presently left to the sensitiveness of the production responsible but the complexity of production is so huge that several delays, pauses, etc., are inevitably produced.

Fig.2 – A phase of the production process in SHELBOX.

Fig.3 – A phase of the production process in SHELBOX.

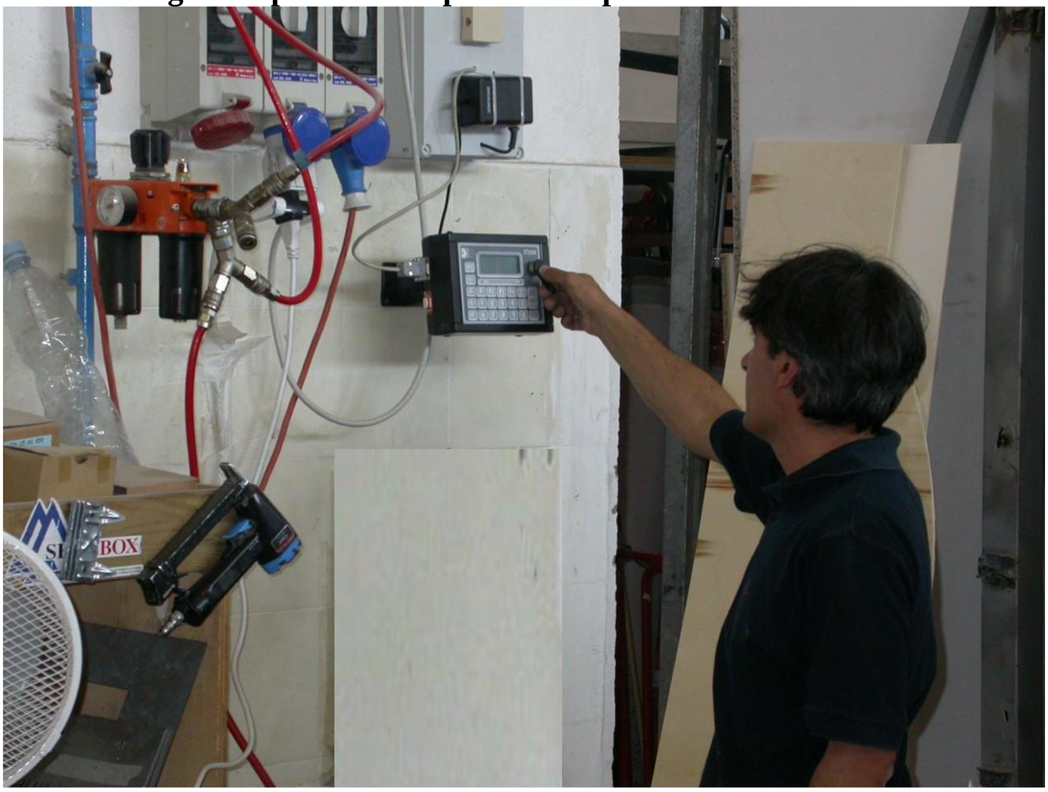

Fig.4 – The access to the OPTAMS microterminal in SHELBOX.

In the following figure, the flow of actions to be taken on available data to produce an optimized plan for resources management is depicted.

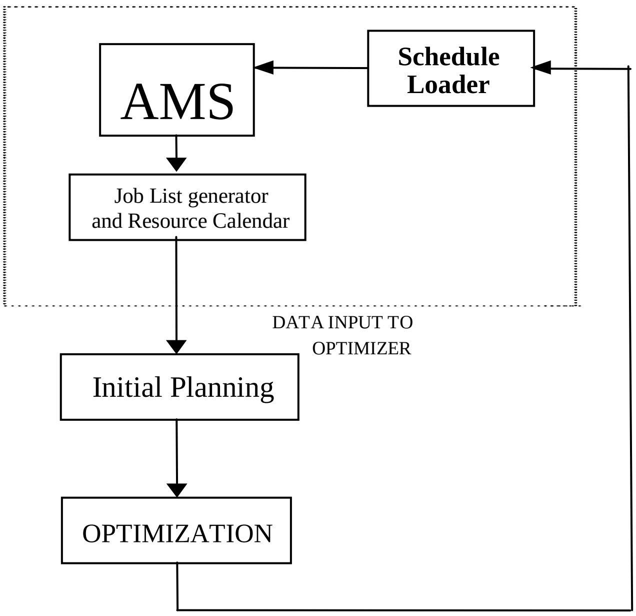

Fig.5 – The control and information flow during the process control of OPTAMS.

Scheduling algorithm

The optimization process addresses the following problem: the firm receives several orders from its clients. Each order might consist of one or more jobs (articles to manufacture). Usually one job must be delivered within a fixed date (deadline). This parameter must be considered important and imposes a constraint on the scheduling algorithm. Every job is liable to different operations (tasks) and each task must be carried out in the right order with respect to some constraints. The entire cycle of the production consists of the several production phases, each of them has to be performed by one or more resources at the same time selected from a larger set/group: a phase, for instance, could be performed either on the machine M0, or on the M1, and need to be performed two people among A, B, C and D. This could happen likewise for the other types of operation. Some constraints need to be considered with regard to the priority of the phases. The aim is to plan the production, minimizing the throughput time, respecting the fixed delivery deadlines, minimizing the costs of production and minimizing the single resources activity fragmentation, with some compromise. An extreme flexibility is required, because either malfunctions or wrong procedures are rather frequent in a plant of such complexity. Therefore it must be possible to re-plan the process at any time to take into account possible differences from what has been planned.

The job shop problem

One of the more complete production system models known in literature is the job shop. In this model every job is characterized by a product cycle requiring the intervention of more different machines/resources; the execution order of the various operations varies from job to job and the resources that have to perform each operation is assigned before the start of the job production according to the plan produced.

The job shop problem can be formalized as follows, given: Several jobs *Ji, (i=1,…,Z),* several machines *rj, (j=1,…,M).* For every job *Ji* is given a set of phases in which consists the job's production cycle: where *pik* is the *k*-th operation *(k=1,…,Kj)* of the job *Ji*. To every phase *pik* is assigned the machine capable to perform such production operation and the related process time *tik*. This is a general model and has been adapted to the real problem. Please see below how this model has been customized for the current implementation of the Tabu Search.

The Tabu Search heuristic

Tabu Search, TS, optimization algorithm was invented by Fred Glover in 1986 [3]. TS algorithms explore some possible solutions of the problem making repeated moves/changes from an *x* solution to another *xn* belonging to the neighborhood *N(x)* of *x*. The neighborhood *N(x)* of the current solution is individuated by the group of solutions, called candidate solutions, that can be reached, from *x*, executing a "move" (for example: exchange of two or more operations assigned to the same machine). The main characteristic of the TS is the introduction of the concept of memory in the search process for the better solution. The memory consists in a list of moves (configurations of the schedule), called Tabu list, that cannot be executed at the current iteration to move towards the next solution. The moves belonging to the Tabu list are moves performed recently or that were performed often in the last iterations. The Tabu list prevents the algorithm from remaining trapped in local minimums and loops which could be created in passing again and again on the same configurations. This can lead it to the space of solutions still unexplored, thus permitting the performing of moves characterized by values of the cost functional major than the one of the current solution. The Tabu state of a move can be changed to an allowed state, if the value of the cost functional associated with it is the minimum between all determined until the current solution (standard criteria). The procedure stops when a fixed number of iterations have been performed.

The TS has been selected to solve the OPTAMS problems according to the results obtained by a comparison with some versions of the Genetic Algorithms, GA. The TS has demonstrated more robustness; furthermore, the main computation costs of both techniques are mainly due to the estimation of the functional terms. With the TS the performance can be estimated incrementally, estimating only the changes and not the whole configuration as needed at each generation of the GA.

The model in the current implementation

This model is a Resource Constrained Project Scheduling (RCPS) problem. In this model there are:

- A set of jobs (articles or group of articles to be manufactured) *I = {j1;…..;jZ}*, where *Z* is the number of jobs to be planned

- Each job consists in a series of production phases: $ji = \{Pi,1;.....;Pi,Li\}$, where i the job index and Li represents the number of production phases in ji job. Jobs are independent from one another, as well as phases related to different jobs. The delivery deadline distinguishes one job from the others, different jobs may have also identical deadlines.
- A phase of a job is constrained by a list of the other phases from the same job. The constraint is meant as follows: in order to perform that phase, all the other phases of the constraint list must be performed first.
- P is indicated either with one or with two indexes. When there are two indexes, one refers to the job the phase belongs to and the other to a progressive index inside the job. When there is only one index to identify univocally the phase, that index is a progressive index among all the phases of all the jobs:

  $$P = \{P1,.....,PS\}, \text{ where } S = \sum_{i=1}^{Z} Li$$

  And P is the set of all phases that have to be scheduled (belonging to different jobs). One production phase is unambiguously indicated in two ways:

  $$Pi \in P \Leftrightarrow Pi \in jk \; (jk \in I) \text{ with } Pi \equiv Pj,k \quad , \quad (1 \leq j \leq Lk)$$

  It is possible to identify one task either by its position within the phase-set or by two indexes which respectively represent the corresponding job and the task's position inside the job itself. Each production phase has a profile describing:

  - Human resources needed in terms of skill and number
  - Material consumable resource needed in terms of foil and list of montage and consumption
  - Machine and position needed to perform the phase.
- **The problem is processing the phases of the jobs in order to map them on a specified time frame of resources availability within the factory.** The plant may have different production pipelines and the job cannot shift from one pipeline to another, being physically constrained to it. On the other hand, human and consumable resources can do that. The resources can be of different type as reported in the next items.
- Human resources are divided in groups of skills: $GR = \{SRG1,.....,SRGR\}$ where $SRGi$ is a group of resources of a certain category/type. Please note that a single resource can belong to more groups, if can play more roles. The factory resources are divided in groups

  $$\forall SRGi \in GR, \; (1 \leq i \leq R), \qquad Ri = \{ri,1;.....;ri,Mi\}$$

  where:

  - Mi indicates the number of single resources inside the skilled resource group *i-th:*
  - $ri,1$ = single resource to which an availability calendar is associated and to which a production phase is mapped in a certain date and time, with these indexes this is the first resource of group i.
  - Every human resource is also characterized by a cost. This information is given with $Cri,1$ = cost of the resource $ri,1$ calculated in euro per minute.
  - These resources have a specific calendar with a given time resolution specifying when it is available, or busy, or free during the year.

- Countable Consumable Resources are used to model the material used in the production. On the basis of such resources' consumption it is possible to plan the creation of orders and the movements from the storage to the production plat. They do not have a calendar since if they are present they can be used.
- Stable Resources are countable and have a calendar. They are used to model:
  - the position of the object under construction along the production pipeline, (for instance: area of painting, area of roof, area of bathroom, etc.), or
  - the use of a specific machine tool used for the production: it can be fixed or mobile and a limited number of them can be available. In these cases, also the consumption of specific tools added to the main tools should be considered. For example, the drills and related tools taken from a temporary storage.

Resource Calendar and the costs

The resource Calendar consists in the information on the status of the human and stable resources for every time slot of the year. Each time slot has duration of 10 minutes. A resource in a certain TIME SLOT can be: NOT_AVAILABLE, FREE, or ALLOCATED. A human resource can be NOT_AVAILABLE, for the periods where the resource is not physically available to work (illness, vacation, Sunday, free turns, nights etc.). When the resource is NOT_AVAILABLE that resource cannot be mapped to work on a phase. The other status values have obvious meanings. The cost of phase *Pi,k* is obtained as multiplication of the hourly cost of the resources, (the cost rate can be different for different resources) for the time those resources allocated on that phase. Total cost of the job *k*-th takes into account the number of the production phases composing the job.

Each phase presents the following main parameters:

- *id* = *<year, cod_subwork>*, a set of two integer numbers which unambiguously identify the phase.
- *ind* = phase index, corresponding to *j* when the phase is represented in the *pj,k* notation: it indicates the phase's position inside the *jk* job.
- Estimated time for the phase.
- Constraints *Pj,k* array of phases that must be performed before the current phase and have greater priority.
- *GRpi* ⊆ *GR* = set of groups needed to perform the phase *Pi.* Ex *(SRG1, SRG2, SRG3).* The group set identifies more resources that can perform an operation needed to execute the phase. The presence of resources groups grant flexibility to the scheduling algorithm since the algorithm can choose a single resource from the specified group to perform a certain operation. To execute a phase more groups and resources can be needed.
- A single phase *Pj,k* may need more type of different resources *(dim{GRpi}).* The groups needed are indicated as *SRGx [a]* with *x* is the index that univocally identifies the *SRG* absolutely and a is the index that varies from 1 to *dim{GRpi}* identifying a certain group needed from a phase. (Ex., the first group needed may be *SRGx[1]*)
- *List_rpi* ⊆ *GRpi* = list of the single resources that work on a phase, with starting date and time, finishing date and time, real time spent on production (between start date and time and finishing date and time there is maybe a not-working night). The sum of the real time slots spent on production gives the time needed for the production on that phase in the

plant.

- *Psuccpi* $\subseteq$ *P* = list of the phases that are less priority (and are thus constrained) by the current phase.
- List of Countable Consumable Resources needed.
- List of Stable Resources needed.
- Starting date and time of the phase *Pi*.
- Finishing date and time of the phase *Pi*. It corresponds to the last finishing date and time of the resources *List_rpi* .
- *tPi,k* = estimated working time of the phase *Pi,k* with *i* phase index of the phase inside the *k-th* job (*tpi* = estimated working time of the phase *Pi,* with *i* univocally pointer index of the phase inside the overall production as above defined). This permits to keep trace of the status about the re-optimization process.
- Real duration of the phase takes account of the time when the resources do not work (for example Sunday). It is calculated as difference of starting and finishing date.
- State of the phase:
    - TO_BE_MAPPED, phases that have to be mapped to resources and currently are not mapped to any resource
    - MAPPED, phases that are already mapped to a resource and scheduled in time
    - RUNNING, phases that are mapped and scheduled and currently in production, during the re-optimization it is important to keep working the single resources on the RUNNING phases.
    - FINISHED , a scheduled phase that has been completed in the real production.

The Initial Solution for the Tabu Search

The TS algorithm needs an initial solution to start. The algorithm used to produce the initial solution is a priority dispatch rules algorithm, a Highest Priority algorithm. Alternatively a deadline monotonic can be also used. At the start-up (or when a re-optimization is performed for adding new jobs and the non already fixed jobs) the jobs are picked up from the list provided by the management tool and re-ordered according to the Job Priority parameter. The Job Priority is an integer number which specifies the priority that has to be given for the execution of job scheduling. It varies from 1 to 10 (from highest to lowest) and is assigned by the administration. In the case of re-optimization, the jobs under execution have to leave unchanged, while those that have not been jet started may be considered as not allocated and re-allocated according to the context changes. Thus during the optimization, Jobs with highest priority must be scheduled and executed as soon as possible, while those with the lower priority and can be scheduled and executed after the others. Some jobs can have the same Job Priority parameter. The estimated Job Priority is related to all the production phases of the job. The Job Priority parameter does not take into account the deadline of the job. If the operator assigns the highest priority to the job with tight deadline it is not assured the deadline is respected in the production plan.
From the initial solution the TS based Optimizer searches a better solution on the bases of a multi-term cost functional. The Optimizer considers only the phases MAPPED and RUNNING. The phases in the state RUNNING are mapped with high priority from the Initial Planner and are not moved from the Optimizer. The algorithm searches better solutions through moves (changes of schedule configurations, assignment and temporal shift of jobs)

and assignments according to the TS algorithm. The search stops when several moves do not improve the solution for a certain number of elaboration cycles or when a maximum elaboration time has passed.

Shift and Assignment Move

The objective of the TS is that of exploring solutions that minimize the cost functional. This search is performed starting from a solution and moving to neighbouring solutions performing some moves. In this case, a move is a shift along the time axis of a production phase, according to the resource calendar. This shift modifies the time allocation of the production phase and the resources that have been assigned to work on that phase. The move is performed by choosing another starting instant for the phase and re-mapping it on the available resources.

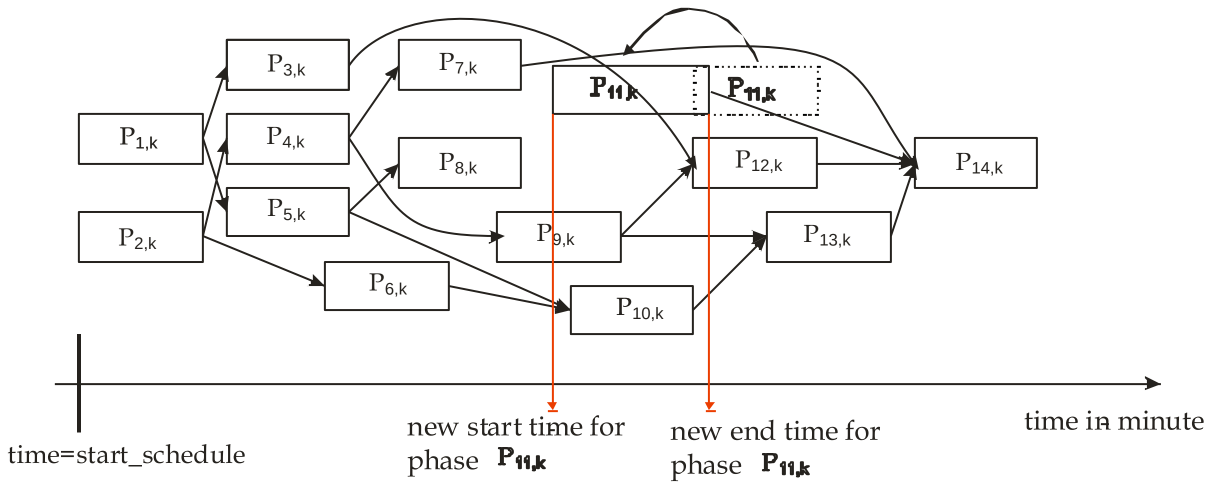

Fig.6 – Moving tasks for the Tabu Search

The Shift move can anticipate or delay the phase. It is possible to explore the phases evaluating whether it is possible to make some anticipations on the starting time, respecting the constraints and determining. By exploring all the phases also for the delays possible monitoring the starting time of the phases that are constrained by the current phase, it is possible to extract a value for the maximum delay. The shift time to apply in the move is determined randomly in the range within the two values above determined. More moves are tried within this range and the functional evaluated, the final move applied is that improving the functional with highest rate, best functional value.

Assignment Move

An assignment move does not change the scheduled starting time of the phase. The resources associated with it are changed, trying other resources from the needed groups to explore the solution space. This move/change of configuration schedule can affect the finishing time of execution of the phase. It is not possible to associate the same resource with two phases in the same time slot. This assignment and shift moves are executed on the phase. The data structure representing the memory of the information needed to the algorithm consists of two arrays of *N* dimension where *N* is the number of phases to optimize. The information needed is:

- “tabu” parameter, for how many iterations it is not possible to execute that move, because its execution previously improved the functional

- Parameter measuring the execution frequency of that move.

At the end of a Shift move it is possible to perform an Assignment move. Different combinations of resources on different production pipelines are tried, and finally the Assignment improving the functional with the highest rate is accepted. Only the moves that are not in the Tabu list can be accepted and after every move the data structure and the variables of the TS are updated.

The OPTAMS tools

In order to see the effective results of the optimization algorithm, a specific user interface has been created. In Figs.7 and 8, the schedules (Gantt diagrams) before and after the optimization are depicted. From their comparison, it is self-evident the time reduction in completing the scheduled production. The graphs showed hereafter are very important to understand the effective impact of the optimization algorithm. The first schedule (see Fig.7) is the one obtained by the first schedule, while the second (see Fig.8) is the result of the TS algorithm, which starts from the first schedule and, through moves, improves the solution, according to the functional cost, the latter being appropriately tuned. In the OPTAMS project the impact has been assessed also by comparing the manual planning with the one performed with TS.

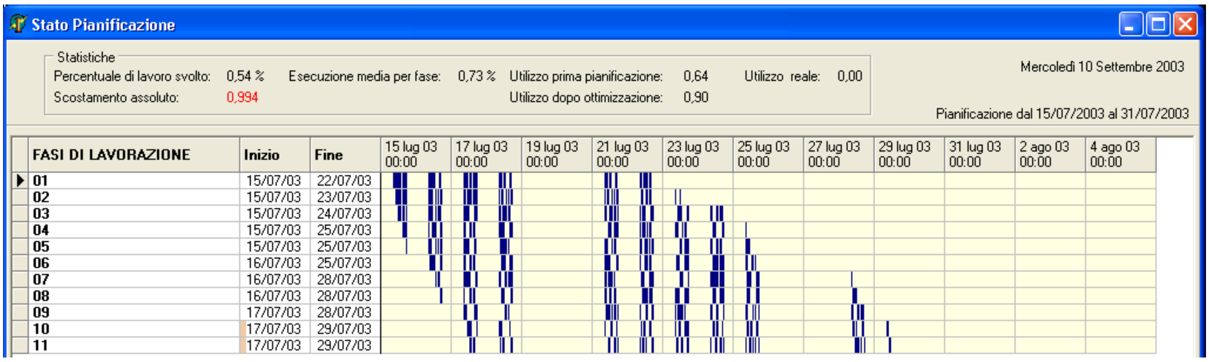

Fig.7 -- Schedule before the optimization, the spaces are: lack of efficiency and also nights, week ends, lunches, etc. The real estimation of efficiency has to be numerically estimated.

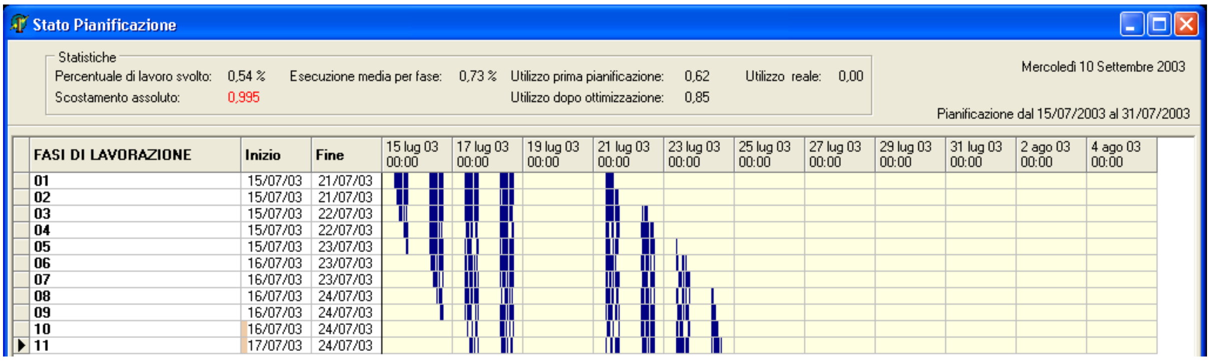

Fig.8 – Schedule reported in Fig.7 after the optimization. The schedule has been compressed by reduced the delivering time and thus the efficiency. The same production has been performed with a lower amount of working days.

In Fig.9, a different view of the Gant diagram is presented. This view can be used to analyse the details associated with each phase of each order.

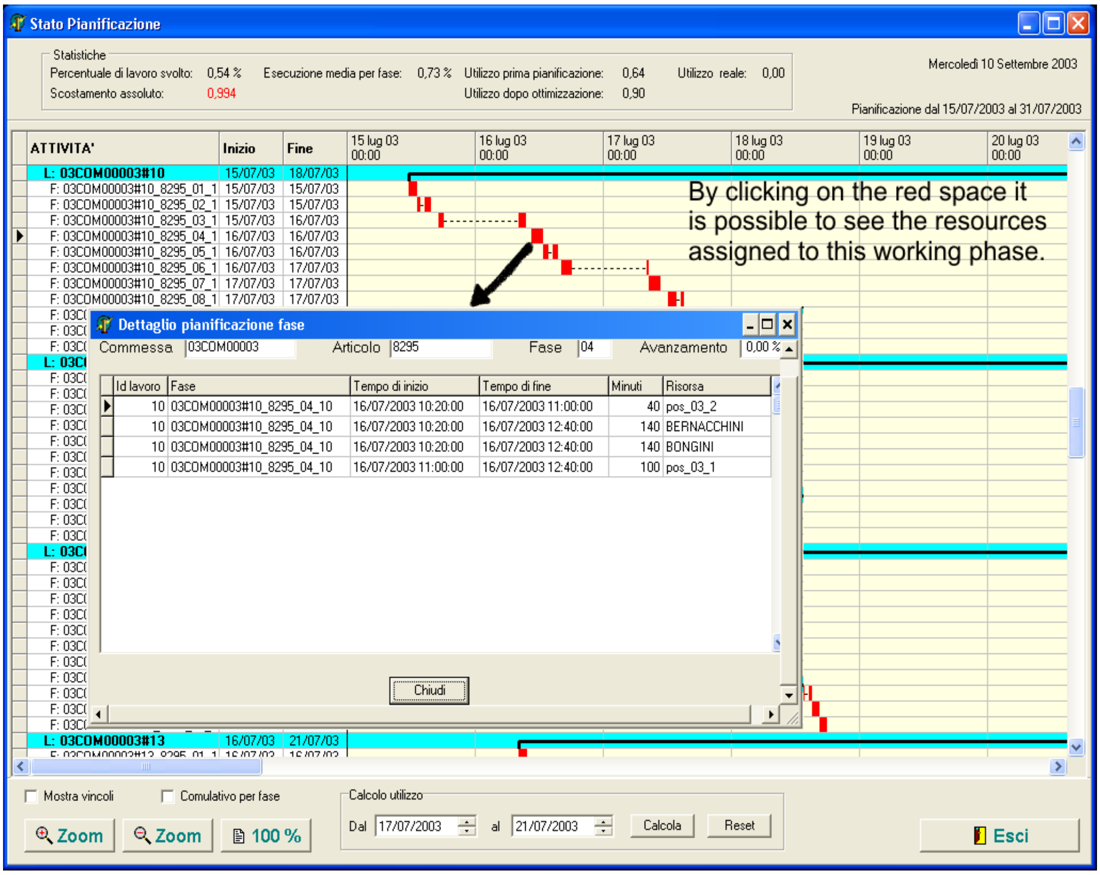

Fig. 9 -- Schedule to see the Gantt of the work to carried out all the phase planned

Functional utilized for the final validation

The optimization process is drawn by the cost functional. In the optimization of OPTAMS workloads several aspects have to taken into account and thus the functional presents several terms that have in some measure minimized at the same time:

$$F = F(Precedence, BiasDeadline, Cmax, Cost)$$

Where:

Precedence: whenever the precedence constraints are violated, moves are not accepted by the algorithm, so the term precedence is always null.

BiasDeadline: functional returns the average value of the discrepancies (advances/delays) for the schedule operations in comparison with their deadlines. Each discrepancy is evaluated by subtracting the ending time of the task from its deadline. This functional may assume both positive and negative values. Positive values indicate a general trend in accordance with the deadlines, while negative values show an opposite trend. Maximizing this term results in favoring schedules with tasks which mostly advance their deadlines.

Cmax: measures the schedule length, subtracting the first starting time from the last ending time.

Cost: of the resources (optimizing the exploitation of less expensive resources), applicable when human resources may have different costs.

In order to adopt the above multiterm functional, a study of the terms is mandatory and in particular attention has to be paid to their values and dynamics. In addition, it is also necessary to evaluate possible repetitions in their estimation so as to optimize the estimation performance. With TS, it is possible to estimate only changes from a configuration to the next one. This allows to reduce the costs for estimating the Functional value to a reasonable amount.

For SHELBOX case, several tests have been executed to understand the impact of all terms on the optimization and to estimate their range values while trying to identify the satisfactory average for managers. Some of the terms have been identified, as being not too much relevant for the production factory needs, in the sense that they impacted on final results in a non positive manner or in a manner that was not satisfactory for SHELBOX. Therefore, after several experiments by using the SHELBOX history of the administrative and planning databases the functional has been tuned to combine only **BiasDeadline** and **Cmax.** The combination has been done by using a linear combination that allows to cancel the initial offset value and normalize the values of the terms:

$$F = KB\ \Delta BiasDeadline + KC\ Cmax$$

Where:

- ***ΔBiasDeadline= BiasDeadline0 – BiasDeadlinek,*** where 0 specifies the initial solution, while ***k*** represents the *k*-th iteration.
- ***KB*** and ***KC*** are the scaling factors estimated on the basis of the dynamics.
- $biasDeadline = \frac{1}{Z}\sum_{i=1}^{Z}(d_{J_i} - end_{J_i})$, and $C_{\max} = \frac{\max_{p_i \subseteq S}\{end_{p_i}\} - \min_{p_i \subseteq S}\{st_{p_i}\}}{\min_{p_i \subseteq S}\{st_{p_i}\}}$

Trend of the functional for the validation test

The graphs reported in Figs.10, 11, and 12 show the trend for the cost functional **KB ΔBiasDeadline** and **KC Cmax,** respectively. The x-axis reports the number of accepted TS moves/configurations, which are the iterations of the optimization process. The value of the functional is reported on the y-axis.

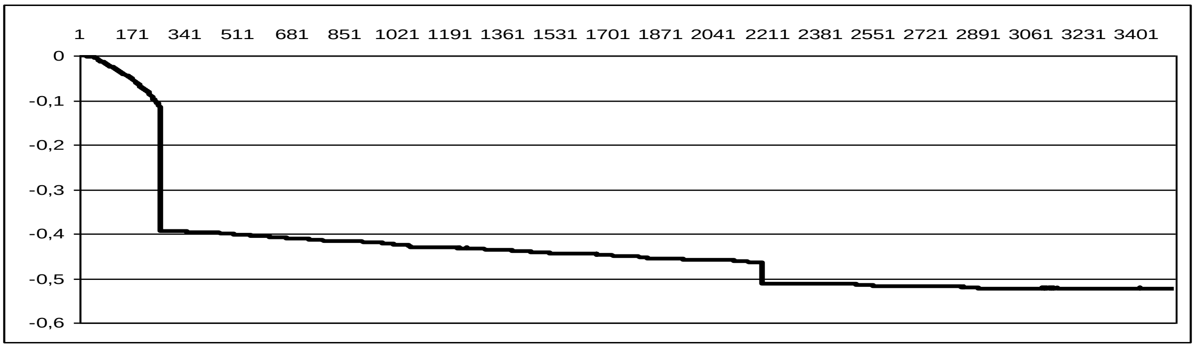

Fig.10 – Trend of the Functional F() value in a typical case (example of Figs.7 and 8).

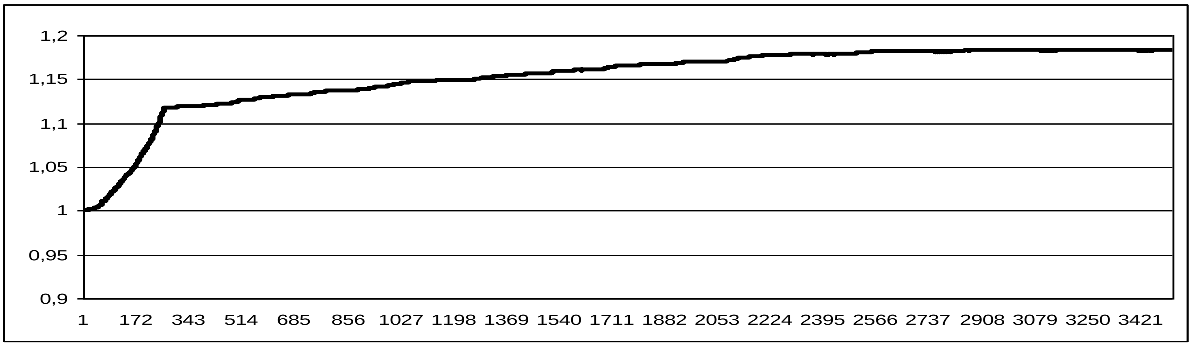

Fig.11 – Trend of term KB ΔBiasDeadline in a typical case (of the same optimization of Fig.10).

Fig.12 – Trend of term KC Cmax in a typical case (of the same optimization of Fig.10).

Formulae to calculate the Efficiency

The estimation of efficiency of the OPTAMS solution has to be estimated with respect to the present conditions of the production process at SHELBOX. The efficiency is for definition lower than 1 and can be expressed in percentage by multiplying the value for 100. The estimation of efficiency, ηs , has to be done on the basis of the real analysis of the production trace according to the following equation by considering a specific time interval for example of 1-2 months:

$$\eta s = \frac{Tprods}{Tavailres}$$

where:

- $Tprods$ is the Time or man power cost of the human resources to perform the production in a given interval of time. For example in a month or more.
- $Tavailres$ is the Time of man power cost of the available human resources to perform the production in a given interval of time.

ηs can be estimated on the basis of

- the schedule manually produced by the personnel of SHELBOX for providing the plan to the production process. It this case it is called, ηm. Some examples of the manual schedule have bee provided by SHELBOX.

- the effective schedule realized on the basis of that produced as a results of the manual scheduling process of SHELLBOX. In that case, it is called ηme. This value is estimated on the basis of the knowledge of the work load in a given period and considering the real values obtained by effectively managing the production by using SHELBOX planning. These values are taken considering the time card of the workers.
- the schedule produced as a first solution by OPTAMS before the application of the Optimization process. In that case, it is called $\eta o1$. This value can be estimated on the basis of the simple knowledge of the work load in a given period without having effectively managed the production by using OPTAMS.
- the schedule produced as a results of the Optimization by OPTAMS. In that case, it is called ηoo. This value can be estimated on the basis of the simple knowledge of the work load in a given period without having effectively managed the production by using OPTAMS.
- the effective schedule effectively realized on the basis of that produced as a results of the Optimization by OPTAMS. In that case, it is called ηoe. This value can be estimated on the basis of the knowledge of the work load in a given period and considering the real values obtained by effectively managing the production by using OPTAMS. These values will be taken by using microTerminal along the production line.

Typically, the following relationships among the above different type of efficiency are verified:

- $\eta me < \eta m$ since some lack of efficiency is introduced in implementing a given schedule. For example, some delay, some unexpected problems in the montages, etc.
- $\eta o1 < \eta oo$ since the optimization algorithm in any case improves the efficiency.
- $\eta oo > \eta oe$ since some lack of efficiency is introduced in implementing a given schedule. For example, some delay, some unexpected problems in the montages, etc.
- $\eta m < \eta oo$ since the optimization algorithms produced for the non trivial problems always better schedules than the manual operator.

In the case of SHELBOX, the analysis has been performed by considering two different periods of workload: highest and low workloads.

The period of highest workload corresponds to February, March, April and May in which they have activities performed by 40 human resources, which have produced about 151 houses in February-March, and from January to April 281. For this period a ηm equal to the 85% (planned manual scheduling) was planned while and effective value of ηme (executed manual scheduling) equal about to 81,9% have been registered.

The different in efficiency from 85% to 81,9% is due to production process problems. A lack of efficiency of the 3,1% is a typical value when the schedule passed from the plan to the realized schedule. This difference is mainly due to:

- people wait for doing their job along the production process,
- overhead for changing type of work
- unexpected problems during the product mounting.

	Manual Planning and management		OPTAMS planning and management	
	Highest workload	Low workload	Highest workload	Low workload
Planned efficiency	ηm =85%	ηm =73%	ηoo = 87%	ηoo = 79,2%
Effective Efficiency	ηme = 81,9%	ηme = 69,5-69,9%	Impossible to estimate	ηoe = 74,7%
Difference in efficiency	3,1%	3,1-3,5%		4,5%

In the above table, please note that it has been impossible to estimate the Effective Efficiency in the case of OPTAMS planning management in present of highest workload since the OPTAMS software has been ready to be used since June and that period is out of the project duration period.

In the period of low workload (June and July), due to changes in the production process, the same efficiency obtained manually planning by considering only the resources used for the production process the efficiency of manual schedule has been measured to be 73%. This has been mainly due to the fact that the personnel have been used to move the plant to a new location and for the reduction of the production process in that period. That period has been chosen to move the plant exactly because it presents a lower workload with respect to the other months. During this period, the OPTMAS has been employed in the production process optimization and management. The OPTMAS has been capable of obtaining the 79,2% of planned efficiency creating an improvement with respect to the manual plan of 73%. In addition, the effective efficiency obtained by executing the schedule produced by the OPTAMS has been of 74,7%. In this case, the difference in efficiency has been higher than that measured from the manual scheduling. This has been identified to be due to the fact that the schedule produced by OPTAMS is more exasperated in terms of allocation and thus any production process problem has a more influence in the changes of efficiency with respect to the non stressed manual planning.

According to the experience of SHELBOX, the manual planning during the period of low workload leads to equal or higher differences in efficiency, typically of 3,1-3,5% as reported in the table. This measures leads to estimate the potential effective efficiency in the case of low workload.

This means that the introduction of OPTAMS has increased the:

- planned efficiency in the case of the low workload: from 73% to 79%, an increment of 6,2%
- effective efficiency in the case of the low workload: from 69,5-69,9% (inferred by past experiences) to 74,7%

This increment in the planned efficiency results in a general increment of efficiency ranging from 4,8% to 5,2%. These values for the improvement of efficiency have been estimated in the low workload period and thus represent a worst case of the improvement of efficiency. In fact, in the period of highest workload the reduction of efficiency is typically the minimum as depicted in the previous table.

This means to have a return of investment in a short time as calculated in the following. In addition, there are other factors that motivate the adoption of OPTAMS and marginally accelerate the return of investment as described in the following section of Business Benefits.

Dissemination

The project dissemination has included different activities developed in interaction with all the partners for the preparation of all the dissemination material. A number of dissemination activities have been carried out during this period with some encouraging results. This co-operation has ensured the production of appropriate dissemination and promotional material, necessary in order to support a widespread and specifically targeted diffusion of the project results. The project have submitted articles to journals, planned participation at stands and designed and published some QA dissemination material. All information dissemination activities have been conducted under the co-ordination of the project co-ordinator: this has guaranteed the delivery of a consistent message to the outside. The Consortium has performed different dissemination activities, designed to achieve the maximal effect, in particular:

- Promotion on Cluster Web Site
- Power-point presentations
- Flyer
- Poster
- Presentation of papers to international Conference of both Control Automation and Computer Science sectors
- Participation at fairs
- Mailing list
- Technology offer inserted in IRC network
- Articles on conferences
- Special promotion and presentation meeting
- Video

Detailed description of dissemination actions

<u>OPTAMS PROMOTION ON CLUSTER WEB PAGES:</u>

Cluster Web Site has been constantly updated and improved. A project presentation has been added together with new relevant information about OPTAMS and its Consortium in order to present the OPTAMS project to possible end-users. The site provides general information about the project and in particular it includes the following information:

  - Introduction
  - Benefits
  - Background
  - The problem
  - The solution
  - Contact details

THE OPTAMS SUCCESS STORY was compiled by the project Consortium; an external consultant made a number of revisions and the story has been published on the Cluster web site in MAY 2002.
Unfortunately, due to a technical problem, the web site statistics were not able to show the number of hits/access made to the success story page.
A copy of the OPTAMS Success Story is shown at the end of this document in the Annex No. 1

POWERPOINT PRESENTATION
The project Consortium has produced a PowerPoint presentation providing a general overview and a detailed analysis of the OPTAMS project results. Specific presentations showing the project progresses have been prepared for the Cluster Review events. These presentations introduce the OPTAMS concept and provide a very useful support during meetings or Workshops.

POSTER
Specific posters have been produced for BIAS, MIT. They will be used also during the next events such as SMAU 2003 and the OPTAMS Regional Seminar.

FLYER
A OPTAMS Project Flyer has been produced by the Consortium. The project flyer is a technical document containing a detailed description and a picture clearly explaining the OPTAMS system functioning. The flyer underwent the Quality Assurance process after which it was printed both in Italian (2100 printed copies) and English (2100 printed copies) and used in the dissemination activities. The flyer is an effective tool to disseminate the OPTAMS project results during the events and by direct mail actions. Through CPR mailing databases the Italian Version of OPTAMS flyer has been sent to 471 companies/organizations (201 companies members of UCIMU - Association of Italian Manufacturers of Machine Tools, Robots, Automation Systems and ancillary products, 41 companies members of ANFIMA - Association of the Italian metal packaging manufacturers, 165 companies members of IIS – Italian Institute of Welding and 64 companies members of ANASTA – Italian Association of Welding Cutting and Related Technology Companies). Only two of these companies expressed formally their non-interest in the OPTAMS system.
The flyers have been distributed at the fairs listed below and with direct mail distribution; SED and SHELBOX sent the flyer to their clients.

ATTENDANCE AT FAIRS / EXHIBITIONS
OPTAMS project and system have been presented with abstracts, presentations and lectures to National and European Conferences, workshops and meetings from each partner.
In particular, the following activities were carried out during the project Period:

- **BIAS** – 19th – 23rd November 2002 – Milan International Exhibition – Automation, Instruments and Microelectronics. More specifically SED prepared their presence at the BIAS Event. They booked a stand (Hall I, Pav. 11, Stand M49) of 16sqm and they presented both VISICON and OPTAMS results, and a set of Flyers has been distributed.

- **MIT** – 19th – 21st February 2003 – Bologna International Exhibition - Manufacturing IT. Participation with OPTAMS project of SED, preparation of a Poster. SED booked a stand 9sqm. 200 Flyers has been distributed.
- **Solutions for Success**- 11th March 2003 - Epsom Racecourse, South-London. A multi-sector partnering opportunity organized, in order to maximise the number of successful partnering meetings between owners and seekers of innovative technology in the South East of England and elsewhere in Europe. The OPTAMS system has been published on the online event catalogue of technologies.

MAILING LISTS

Mailing list of SED has been used during the project validation to inform its customers of the availability of the prototype for their validation and to stimulate the visit of the prototype.

For the mailing has been used the:

- list of clients of SED and contacts of (manufacturing industries that implements AMS system). The have been contacted in order to make them aware about the new technology of SED and of the fact that OPTAMS architecture can be applied in several different fields, as also stated in the technology offer.

OPTAMS TECHNOLOGY OFFER

The OPTAMS system Technology Offer was compiled and inserted in the Innovation Relay Centre (IRC) Bulletin Board System in May 2002. The technology offer has been circulated to 68 IRCs (which includes a total of 220 organisations) who then forward the information to their clients. The technology offer will also be made available on the Eutist Cluster web site.

One Expression of interest has been received from a French company. More details have been sent to the interested company. At the end of this document, Annex No. 2. shows the text of the specific form for defining the OPTAMS Technology Offer.

ARTICLES

3 official publications have been prepared for which each partner gave his contribution. 2 more articles/presentations are planned. They will be submitted (in the name of OPTAMS Consortium) to European or International papers/events:

- Article " OPTIMIZATION OF PRODUCTION PLAN ", European Integrated machine Vision, EUTIST-IMV, Vol.4, 2003;
- Published by CPR on ATA News "Advanced Tertiary Companies Journal"-(Issue Dec. 2002), an article about IMV technologies together with the presentation of OPTAMS project
- An article about IMV technologies together with the presentation of OPTAMS project has been published on the Arnovalley Community Portal (the Tuscany business and technology Internet Portal) together with the Italian OPTAMS flyer available to be downloaded, the article has been submitted by CPR
- SMAU press release in collaboration with EXPANSIV's PR agency GBCS. The article presents OPTAMS project and its participation at SMAU2003 The press release has been distributed at European level through GBCS network. CPR translated the article and carried out its distribution in Italy.
- Article: submitted to ICECCS2004 IEEE Conference

- Article: planned to be submitted to an international journal as soon as the validation phase will produce the project results.

VIDEO
- Production of a demonstration video to be used as a support during dissemination events.

Future Dissemination Activities

Cultural and Scientific activities
In this category are included all the actions aiming to disseminate the vast amount of knowledge produced during the OPTAMS project, including the presentation of the project itself. The expected result is to introduce the OPTAMS concept and to create a general public demand for this kind of service.
According to this objective, even after the project end, the OPTAMS partners will continue to perform a series of targeted activities. Each partner will be in charge of identifying, selecting and keeping track of future dissemination opportunities, such as: participation at conferences and seminars, production of articles on selected magazines (addressing not only the scientific sector but also the managerial) and on general magazines (for a wide audience). Information about the results achieved through these activities will be made available to all the partners.
A public final report of the project has been produced to be disseminated during conferences and workshops. The report is devoted to the presentation of final data and test results; it underlines the advantages which can be obtained by adopting the OPTAMS process.

Promotion, marketing and sales activities
Marketing and sales activities will be organized in connection with the following objectives:
- disseminate the project results considering technical, cultural and commercial levels
- rise awareness about the new model proposed at the European level.
- present the project as a new production planning technique.

OPTAMS Flyers, IV EIMV, e-newsletter, etc. will be distributed :
- To several of the medium-sized and large firms (mainly machine producers and machine end-users), by using National and European Industrial Associations such as: UCIMU, CECIMO, etc.
- To several of the medium-sized and large firms by using Kompass database
- During the 8th Conference of the Italian Association Artificial Intelligence, 23rd-26th September 2003 "*L. Fibonacci*" University of Pisa.
- During Company Visits that will be carried out in the framework of EXPANSIV activity by CPR

UPCOMING EVENTS IN COLLABORATION WITH EXPANSIV

International Event:
- **SMAU 2003** – Milan – 2-6 October 2003 www.smau.it. The project will be presented within three different contexts: Genius, Match 2003, IST 2003,

Regional Event:

- The partners have organized a public presentation of OPTAMS solution at SED in Empoli (Florence), on 24th September 2003. Representatives of several medium-sized and large Italian and European manufacturing industries will attend. A questionnaire will be distributed to the companies attending the event.

Conclusions

The possibilities of the computer science technology are, currently, the integrated management of the whole business “flow”, from the planning of the storehouse, from the plant to book-keeping, from the laboratory to the management. The time is one of the most important variables in the constitution of the business costs. It is also a variable that**,** unlike the availability of materials**,** depends on the organisational ability of the enterprise and on a correct management of the personnel, of tools, etc. The main purpose of AMS system is to determine a precise estimation of certain production costs for each single product by means of the management of all the production resources**,** like human resources, machines and materials in the different phases of production.

Manufacturing industries exploit resources, material, personnel, machines tools, robots, etc., in a very flexible way. To this end, the resource management has to be effective in order to have competitive costs. For this, off-line resource planning tools are typically used. Most of them can plan and optimize the production of stable production pipelines (the same set of products for several months). Whereas, when the production is strongly differentiated (this being the SHELBOX case) the tools fail in that purpose. In order to solve the explained problems, OPTAMS integrates an on-line optimization technique with an on-line distributed resource manager called AMS (All Monitor System), based on barcode pens, micro-terminals and identification keys for managing people and CANbus for managing machines. OPTAMS covers MRP, MES areas and the level of Control Level related to the needs of the factories having differentiated productions, the subsequent need to re-optimize often and multi production pipelines with a flexible allocation of people who may shift from a production pipeline to another if necessary. This solution increased efficiency of more than 5%, by using a multiterm functional that could find the right arrangement between satisfactory deadlines and production costs.

In addition, the insertion of the acquisition system of production data permits to obtain in real time: the data related to the personnel, the collection of machines’ data, the advancement of the production, the valorisation of the production, the presence of a bidirectional messages Production Office system - Commitment/phase/operator for the integration of the quality system and the Analysis and Reporting. One of the peculiar features of the AMS system is its ability to be configured in order to adapt it to different production systems. This is a clear advantage for companies that decide to adopt AMS, because they have no difficulties in inserting it in the productive environment.

Another important support of the resource management can give to the company a direct connection with administrative office of the company. With a resource manager (such as AMS) the administrative office easily communicates to the client the delivery date of his order simply inserting it in the production process. A quick answer on the delivery times is often the winning strategy since the price is fixed by the market. Another important aspect of resource management systems is the possibility to set-up the quality control of the produced products. Through this procedure it can be possible to have a trace of the product life cycle taking into account both materials that have been used for their creation and the resources that have intervened in the production

Business Benefit
In order to estimate the ROI for the adoption of OPTAMS several aspects have to be taken into account. The cost of the personnel that work on the physical production of the houses is fixed for all the people involved and is of 12,97 Euro per hour. The personnel work 173 hours per month and has about 268 hours of vacation and permissions in the year. The production is performed with 40 people. This means to have a cost of personnel per month of about 89752,40 Euro for producing about 70 mobile houses, that lead to have a cost of personnel for mobile house of about: 1282,17 Euro.

The mean costs for the production of each mobile house is about 9830,00 Euro including costs of material and that of process.
The mean cost of material to produce a mobile house is about 7600,00 Euro.
The mean value of the industrial costs per mobile home is about 2230,00 Euro: which consist of the cost of personnel for 1282,17 Euro, while the remaining costs are the general costs, energy costs, fixed commercial costs, maintenance of tools, depreciation of equipments, consumable material, administrative costs, etc., excluding the cost of distribution, mentioned in the following.

The number of houses that have been produced in the period of January, February, March and April is 281. An average of about 70 houses per month has been produced.
In February and March have been produced 151 mobile houses, while in January-April 281. The cost of the production performed in the first 4 months of the year is about 2762230 Euro, for 281 houses. The market value of the production performed is about 3249682. This means that an incoming of 1734,71 euro per home is obtained, that is about a 17,6 % per home. In this 17,6%, the costs for the transportation, that of distribution (commission, sale) and the profits are included. The costs of distribution and transportation are about the 6% of the final price, and thus they impact in the cost of each mobile house for about 694,00 Euro.

Mean value for each mobile house	**Costs in Euros**
Material and consumables for producing a single house	7600,00
Personnel, gross salary including taxes, permissions, etc.	1282,00
General costs, energy costs, fixed commercial costs, administrative, etc.	948,00
Distribution and transportation	694,00
Incoming profit	1040,71
Total price of the Mobile house	11564,00

According to the validation numbers

In order to estimate the ROI, the estimated Improvement of Efficiency has to be considered. According to the numbers reported in the previous section the increment in the planned efficiency results in a general increment of efficiency ranging from 4,8% to 5,2%.

An increment of efficiency from 4,8% to 5,2% leads to have in the same time an increment of production corresponding to that percentage. As explained in the previous section, the 4,8% represents the worst case obtained in the low workload period, also applied as a worst case for the period of high workload. This means that the insertion of OPTAMS will lead to have an increment of production with the same personnel costs.

An increment from 4,8% to 5,2% in efficiency means to increment the production from 3,36 to 3,64 mobile house per month with the same personnel cost. The personnel cost per mobile house is about 1282 Euro. This is a neat increment of saving of personnel costs ranging from 4307,52 to 4666,48 Euro per month. In addition, the increment of production leads also to increment the profit from 3494,4 to 3785,6 Euro since more mobile houses can be sold.

	min	max	
Increment of efficiency	4,80%	5,20%	Percentage
Increment of the number of mobile houses per month	3,36	3,64	Number
saved personnel by producing more mobile house with the same personnel per month	4307,52	4666,48	Euro
increment of profit in delivering and sale the additionally produced mobile houses per month	3494,40	3785,60	Euro
Total increment of incoming per month	7801,92	8452,08	Euro

The final price of OPTAMS will be of about 60000 including 10 terminals. This means that the ROI in the worst case can be obtained in two manners:

- with the increment of production, saving the costs of personnel, without considering the increment of profit: 60000/4307,52 = 13,9 months.
- with the increment of production including the increment of profit: 60000/7801,92 = 7,69 months.

Please note that, the total increment of income per month (in the worst case, 7801 Euro per month) will produce (after the ROI) an additional profit per month of 10,7%. Presently the profit is about 8,9 %. Thus with OPTAMS it will pass to close 20%.

In addition, there are several other factors that accelerate the return of investment and thus the interest in OPTAMS. Other improvements and rationales to pass at OPTAMS instead of continue to use the present manual mechanism are:

Other improvements and rationales related to OPTAMS are:

- the reduction of time needed for producing a next period schedule . At present the person assigned to this work needs about 1 week to prepare the schedule for the next two months and the schedule is revised every month. With OPTAMS, an automatic process, under the supervision offered by the same skilled personnel, can produce better schedule in shorter time, 2 days. This will free a part of the time of a very skilled person. This time can be used for planning the production of another plant of SHELBOX.

- The possibility of producing the re-planning with optimization more often than once monthly. This will increase the production control, the flexibility and the recovery of faulty problems such as the lack of a given component for the production process, etc. The schedule may include some phases representing the orders. They may be all allocated to the order office. This will allow scheduling also the work of the ordering with the consequent reduction of goods on hand, only for the basic matters.
- The automatic production of the report summarizing the activities performed by each single person working on the production plat. Presently this process is performed by producing cards that have to rewritten by hand on a computer for processing them for quality and production control. With OPTAMS the log of activity and the estimation of efficiency will be automatic.
- The reduction of fragmentation in the personnel work. Presently the personnel are moved from one phase to another when needed, when a bubble is observed in the production process. This can be planned since the beginning reducing the overhead of the change of resource allocation and thus increasing the production process efficiency.

Contact details
Partners:

- **SED: Special Electronic Design** S.r.L. Certaldo, Italy, (project co-ordinator and technology transfer receiver). The project co-ordinator is the SED. SED plays the role of technology transfer receiver especially regarding the hardware and software aspects. SED builds automatic controls since 1975 and has used several times the skills of DSI for acquiring innovative technologies in the field of microprocessor-based systems, embedded systems, automatic control, object oriented, software engineering, etc. Example of this collaboration are the projects OFCOMP (DIM 45 MEPI ESPRIT III), INDEX-DSP and MUPAAC ESPRIT IV in HPCN.
- **DSI: Dipartimento di Sistemi e Informatica**, Università degli Studi di Firenze, (University of Florence), Firenze, Italy (vision based technology provider). The DSI plays the role of technology provider: computer vision, image analysis and processing, software engineering. As research institute the duty of DSI is to be always in advance with respect to the industries.
- **CPR: Consorzio Pisa Ricerche, Pisa, Italy**. CPR is the link of the consortium with the project cluster of the EC and a skilled support for the dissemination of results.
- **SHELBOX, CERTALDO, Italy.** SHELBOX produces about 600 mobile houses per year. Sometimes clients request variations on standard products of SHELBOX. The effort of the firm to produce one mobile house is estimated in about 60-70 hours. The production process consists of assembly phases as reported in the table below. The final year balance of the costs outlines how the hours needed during the year are sensibly more than what have been planned in advance on the basis of the average hours needs per house.

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Project Numbers
Url: http://www.eutist-imv.com
Project Duration: 19 Months
Start: January 1, 2002 – July 31, 2003
Overall cost: 430876 Euro
Commission financial contribution: 228098 Euro

Annex No 1: OPTAMS SUCCESS STORY

OPTIMIZATION OF PRODUCTION PLAN

OPTAMS (OPTimised All Monitor System**.** On-line optimizer and resource manger for production control)

Summary

OPTAMS is an on-line optimization tool integrated with a resource management system, called AMS (All Monitor System). OPTAMS (Optimizer and AMS) is directly capable controlling consumption of material, tools and personnel resources. This solves production process problems for companies that have a strongly differentiated and flexible production such as SMEs.

Most of the ERP (Enterprise Resource Planning) products are typically off-line, thus they are suitable for planning a stable (a-regime) production process, presenting repetitive cyclic activities. On the contrary, OPTAMS is an on-line optimization tool that permits the monitoring and the management of production process. In addition, every time that a change of the resource condition, the re-optimization of the whole process can be applied considering changes and current status of resources. This really permits to save time and money in the production without stopping the process.

The benefits

OPTAMS impacts on the management of the production budgets and increase general production efficiency. By means of the optimization, the company is able to reduce and control the maximum workloads permitted by the structure. Consequently it is possible to decide if there is the need to hire other personnel in order to satisfy the new requirements**,** avoiding to turn to extraordinary work that has a higher cost and does not help the increment of occupation.

OPTAMS has the capability of controlling flexible productions**,** adapting the production to the available resources in quasi real-time. OPTAMS presents a cost very low solution with respect to well-know commercial products for the production control. Moreover, OPTAMS is effective and precise in controlling human resources and machine tools, respect to other product.

Background

The production time is one of the most important factors of the product costs. It is also a variable that**,** unlike the availability of materials**,** depends on the organizational ability of the enterprise and on a correct management of personnel, of tools, and machinery, etc.

The main purpose of a resource manager system is to determine a precise estimation of certain production costs for each single product by means of the management of all the production resources**,** like human resources, machines and materials in the different production phases. In addition, the monitoring of production data related to the personnel, the machines, and the material resources permits a more effective integration and management of the production process. In some cases, the integration may involve the production of Analysis and Reporting and even a more precise and effective planning of orders, thus allowing the reducing of the storage. Through the integrating of resource manager system and on-line optimization technique is possible to increase the production efficiency.

The problem

The optimization process regards the following problem: the firm receives several orders from its clients. Each order might consist of one or more jobs (articles to manufacture). Usually one job must be delivered within a fixed date (deadline). This parameter imposes constraints on the scheduling algorithm. Every job is liable to different operations (tasks) and each task must be carried out in the right order.

The entire cycle of the production consists of the several production phases, each corresponding to one or more resources which can perform the related operation: a phase, for instance, could be performed on different machines or by different people. This could happen likewise for the other types of operation. Some constraints need to be considered with regard to the priority of the phases.

The aim is to plan the production, minimizing the throughput time, respecting the fixed delivery deadlines, minimizing the costs of production and minimizing the single resources activity fragmentation. An extreme flexibility is required, because either malfunctions or wrong procedures are rather frequent in a plant of such complexity. Therefore it must be possible to re-plan the process at any time to take into account possible differences from what has been planned.

The solution

To cope with the above problems we have realized OPTAMS solutions and architecture. OPTAMS is an on-line optimization tool integrated with a resource management system, called AMS. OPTAMS is an on-line optimization tool that permits the monitoring and the management of production process, controlling all kind of resources. Every change in resource condition may be programmed to start a re-optimization of the whole process.

In OPTAMS complete architecture comprised of two main software component: Optimizer and Process Manager AMS. The Optimizer implements the on-line optimizer/re-optimizer taking into account the available resources and their status. This component implements a specific optimization based on TABU search. Tabu Search optimization algorithm was invented by Fred Glover in 1986. This iterative algorithm explores some possible solutions of the problem (configuration of the plan) making repeated moves from a solution to another. The next solution is individuated by the group of solutions, called candidate solutions, that can be reached, from *x*, executing a "move" (for example: exchange of two or more operations assigned to the same machine, making permutations, etc.). The main characteristic of the Tabu Search is the introduction of the concept of memory in the search process of the better solution. The memory consists of a list of moves, called *Tabu list*, that cannot be executed at the current iteration to move towards the next solution. The moves belonging to the Tabu list are moves performed recently or that were performed frequently in the last iterations. The memory structure impedes to the algorithm to remain trapped in local minimums, leading it to the space of solutions still unexplored, permitting the performing of moves characterized by values of the cost functional major than that of the current solution. The Tabu state of a move can be changed to an allowed state if the value of the cost functional associated with it is the minimum between all determined until the current solution (standard criteria). The procedure stops when a fixed number of iterations have been performed. The Tabu Search is the elected method to solve the scheduling problem. The advantages in a comparison with other techniques are robustness and the rapidity.

The Process Manager AMS attempts to manage the production according to the planned activities defined by the Optimizer. It is able to take into account of the actual values measured on the production process, through the time, such as changes in starting and ending time, respect the planned. When critical changes and variations are recorded**,** then a re-optimization phase is needed. Planned and real measures are used by the Optimizer to perform or not a re-optimization on the basis on selectable criteria.

Contact details

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Annex No. 2: TEXT OF THE FORM FOR THE OPTAMS TECHNOLOGY OFFER

TECHNOLOGY OFFER VER:2.1

DEADLINE (DD/MM/YY): maximum of 1 year

TITLE:

OPTAMS (OPTIMIZED ALL MONITOR SYSTEM)- ARCHITECTURE AND TOOLS FOR IMPLEMENTING AN ON-LINE OPTIMIZER.

ABSTRACT:
Manufacturing industries integrate in their production pipelines different resources: material, personnel, machine tools, robots, etc. The resource management has to be effective to have market competitive costs. To this end, on-line optimizers and resource managers are needed. OPTAMS integrate on-line optimization techniques of DSI partner with the on-line distributed resource manager of SED partner, called AMS (All Monitor System).

DESCRIPTION:
OPTAMS integrates an on-line optimization technique of DSI partner with the on-line distributed resource manager of SED partner called AMS (All Monitor System). OPTAMS will be based on barcode pens, micro-terminals and identification keys for managing people and CANbus for managing machines. OPTAMS is collocated among the MRP (Manufactoring Resource Planning) MES (Manufacturing Execution System) areas and the level of control related to the needs of the factories that present differentiate productions with the necessity of frequent re-optimizations.
The on-line optimizer/re-optimizer takes into account the Available Resources and their status and measuring. A resource available at a given time instant may disappear during the production process for faults or simply since it has been finished (for material). In some cases, a personnel problem may occur constraining the person to leave the production process for minutes, hours or days. Therefore, on-line re-optimization is mandatory. The optimizer produces a list of PLANNED ACTIVITIES on the basis of the Activities Database containing the committed works acquired from the Administrative Server and commercial part of the factory. This activity is directly obtained from AMS product of SED. The committed works are transformed in real activities by the Optimizer on the basis of several criteria: deadlines, available resources, strategic actions of the company, available reserves, etc
The on-line optimizer integrated in OPTAMS is based on Taboo Search.

INNOVATIVE ASPECTS:
Recently, new optimization techniques have been invented in order to reduce the time to produce suitable solutions. These are typically sub-optimal but are produced with a very short time of computation. These innovations have permitted big improvements in the quality of solutions and in the velocity of their production. They permitted to manage problems that before could not be considered as the *flexible job shop problem* or the *resource constrained project scheduling*. Some examples of the innovative algorithms recently developed include the *simulated annealing*, the *tabu search*, the *genetic algorithms*, and the *genetic local search*. The strategies that are adopted by these techniques are called *local research techniques*.
The on-line optimizer integrated in OPTAMS will be based on Taboo Search.

MAIN ADVANTAGES:
Currently, off-line resource planning tools are typically used, most of them are capable to plan and optimize the production of stable production pipelines (the same set of products for several months). When the production is strongly differentiated these tools are unsuitable, OPTAMS solve this problem. OPTAMS impacts on the management of the production budgets. By means of the optimization, the company is capable to reduce and control the maximum workloads permitted by the structure. Consequently it is possible to decide if there is the need to hire other personnel in order to satisfy the new requirements, avoiding to turn to extraordinary work that has a higher cost.

SUBJECT CLASSIFICATION CODES:
Keywords: Database, Information Technology, Industrial Engineering, Manufactoring Techniquis Artificial Intelligence

CURRENT STAGE OF DEVELOPMENT: (ONLY one choice)

☒ Development phase – laboratory tested
☐ Available for demonstration – field tested
☐ Already on the market

INTELLECTUAL PROPERTY RIGHTS: (ONLY one choice)

☐ Patent(s) applied for but not yet granted
☐ Patent(s) granted
☐ Copyright(s) registered
☒ Secret Know-How
☐ Exclusive rights
☐ Others

COMMENTS:

- Current stage of development

- Exploitation of RTD results

- Intellectual Property Rights (countries, date, ref...)

ORGANISATION/COMPANY:

Type
☐ Research Institute/University
☐ Technical Centre/Technology transfer Centre
☒ Industry
☐ Other
If other, please specify:

Size

☒ < 50
☐ 50-249
☐ 250-500
☐ >500

BRIEF MARKET APPLICATION CODES (multiple selection):

Industry

- ☒ Industrial Manufacture
- ☐ Transport
- ☐ Aerospace Technology
- ☐ Construction Technology
- ☐ Materials Technology
- ☐ Chemical Industry
- ☐ Automation/Robotics
- ☐ Heavy Metals Industry, smelting

Information Technology

- ☐ Electronics, Microelectronics
- ☒ Information processing, Information systems
- ☐ Telecommunications

☐ **Energy**

Biological Sciences

- ☐ Medicine, health
- ☐ Biotechnology
- ☐ Veterinary
- ☐ Pharmaceutical/Cosmetics

Environment

- ☐ Environment protection
- ☐ Waste management
- ☐ Nuclear Safety - Radiation protection - Radioactiv

Agricultural and marine resources and products

- ☐ Agriculture - forestry
- ☐ Food - agroindustry
- ☐ Fisheries, resources of the sea

Measurements and standards

- ☒ Measurement methods
- ☐ Reference materials
- ☐ Standards - quality

☐ **OTHERS** *(specify)*

DETAILED MARKET APPLICATION CODES:

Keywords: Industrial measurement, System software, Database and file management, Applications software, Manufactoring Industrial, Artificial Intellignece related software.

MARKET APPLICATIONS - HIGHLIGHTS:

Comments:

COOPERATION TYPE: (please tick more than one if necessary)

- ☒ Financial resources
- ☒ Joint venture agreement
- ☐ Licence agreement,
- ☐ Manufacturing agreement (subcontracting & co-contracting)
- ☐ Commercial agreement with technical assistance
- ☐ Technical co-operation
- ☐ Others *(specify)*

COMMENTS:

- Type of partner sought:

- Specific area of activity of the partner

- Task to be perfomed

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