“MODELLING AND SIMULATION IN TECHNOLOGICAL AND EMERGING FIELDS: EMERGING CHALLENGES”

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Summary

Simulation and Modelling activities have been an integral part of the traditional activities in all branches of the Engineering profession. In the last fifteen years, we have witnessed the use of such science based tools in other areas such as management and finance, social studies, environment, transport etc. “Soft Systems” approaches are relevant to the early stages of problem definition of complex problems, but they do not provide the hard analytic tools for evaluation of alternatives and definition of optimal solutions. The generalisation of the field of applications where “engineering type solutions” are sought for non-traditional engineering problems, makes the need for modelling and simulation of the emerging applications of paramount importance. This paper, aims to contribute in the specification of the modelling and simulation research needs of the vast area of challenging emerging applications.

1. Background: Emerging Needs

Modelling and simulation of technological and general nature processes has been an on-going research activity for many years. The generalisation of the field of applications through ICT and the important developments emerging science fields (Genetitics, Systems Biology, Quantum Computing etc) introduce new problems with increased complexity, driven by societal needs and scientific opportunities. For example, computing power provides the potential for the development of integrated solutions to large scale problems such as air traffic management, management of entire supply chains, e-commerce applications, management of energy systems etc; in such fields, the multi-component and large dimensions of the processes involved are reasons for forms of complexity due to *dimensionality* and *multi-component* nature. Addressing issues of integration of operations in industrial systems introduces the need for linking models of different nature and leads to a new form of complexity due to the *hybrid* nature of composite models. In the engineering area, man-made systems are increasingly complicated and system design moves to the edge of a complexity barrier by considering the micro-, nano-systems types of developments. We now need novel methods how we can design them as elements, builds composite systems from components while still keep them maintainable and reliable Modelling and simulation techniques developed in traditional science and engineering disciplines have to be adjusted and developed for the new challenging fields of Systems, Molecular Biology, DNA computing, Quantum computing and Electronics, Micro- Nano-Systems etc. New revolutionary methods of data acquisition are providing immense amounts of information in fields such as molecular biology and genetics. More powerful means of exploiting this information could advance our understanding of living systems, as well as our ability to design effective therapeutics for them, to entirely new levels. In social systems, scientific assessments are needed to inform decisions about inherently complex matters such as national security, public health, assessment of deployment of new technologies and global warming and protection of the environmental. Meeting these diverse needs will strongly influence the course of science and technology in the coming decades and leads to the emergence of new engineering disciplines requiring a richer set of modelling and simulation tools.

Existing techniques for Modelling and Simulation of problems such as societal infrastructures, molecular networks, or functioning of complex chip designs need to handle interactions among very large numbers of heterogeneous, interacting entities. Furthermore, such problems may be characterised by incomplete knowledge as far as their basic components and their interconnections, which may be not be fixed but change during the life cycle of the system. New *approaches to modelling/simulation and data analysis* are necessary. We need new paradigms for modelling and simulating complex systems, as the increase in computational power does not compensate for the increase in scale of problems we have to deal with. The modelling and simulation of the classes of new complex systems is a prerequisite to the effort of development methodology for analysis and eventually design of the new forms of complex systems.

2. Complexity in Emerging Applications

Complex Systems is a term that emerges in many disciplines and domains and has many interpretations, implications and problems associated with it. The specific domain provides dominant features and characterise the nature of problems to be considered. A very significant class of complexity issues is that linked to design and operation of industrial systems, but new forms of complexity emerge in fields like Molecular Biology, Genetics, Micro- Nano-systems, Quantum electronics and computing, Systems Biology etc. We focus here on the engineering field and its embedding in the general production system and related societal aspects. The distinguishing features of this large and very general problem area is the need for a systemic approach, the close link between modelling, system structure and properties, measurement-information and control-decision making-management structures. This area contains a number a generic, complex nature type problems which underpin the development of future methodologies and associated technologies for technological problems. However, understanding the nature of such forms of complexity has important implications for many other fields due to the transferability of the framework and concepts and some extend part of the results.

A common characteristic of many technological, production, environmental, societal, financial, business problems, etc., is their complex nature which is manifested in many different ways which include:

(a) Lack of knowledge, or difficulties in characterising the behaviour of the basic process, or subprocesses (*Unit Behavioural Complexity*).
(b) Complexity of computational engine associated with a sub-process (*Computational Complexity*).
(c) Difficulties in characterising the interconnection topology of subp-rocesses and/or variability, uncertainty of this topology during the system lifecycle (*Interconnection Topology Complexity*).
(d) Large scale dimensionality and possibly multi-component character that impacts on methodologies and computations (*Large Scale – Multi-component Complexity*).
(e) Heterogeneous nature of sub-processes, which in a given interconnection topology, results in hybrid forms of overall behaviour (*Hybrid Behavioural Complexity*).
(f) Organisational alternatives for the functioning, information and decision making (control) structures in respond to goals and operational requirements (*Organisational Complexity*).
(g) Variability and/or uncertainty on the system's environment during the lifecycle (changing goals, requirements, disturbances, structural changes) which require flexibility in organisation and operability (*Lifecycle Complexity*).
(h) Variability of the system's environment due to changes of disturbances, as well as emergence of events affecting the structure of the system *(Environment Induced Complexity).*
(i) Evolution, growing of a system shell and final emergence of a final system during a physical, or design process (*Structure Evolution Complexity).*

The area of complex systems is multidimensional and has a multidisciplinary character. Understanding and eventually managing the different classes of complexity requires modelling and simulation and development of systemic approaches, based on formal methodologies, which allow the description of the transition from the unit to the whole and provide the means for understanding the evolution of emergent properties.

4. The field of Simulation

By "Simulation" we mean the construction of models of systems, based on (often incomplete) empirical data, and then executing these models on a computer to examine to examine aspects the dynamics and aspects of the behaviour of the system. This is particularly important when analytical solutions are very difficult to obtain. For many systems, simulation is the only practical method for developing some understanding of their properties.

Usually, simulations complement experimentation and very frequently complement the experimental knowledge and as verifiers of design activities. To achieve real understanding simulations have to be based on sound mathematical foundations. A simulation is always based on a model and a good simulation implies that the underlying model is a good approximation of the reality that approximates.

Despite the availability of high speed computers, very frequently high quality physical models are often sacrificed for the sake of computational speed and power. Computer power is not properly utilised and the majority of scientific simulations describe coarse approximations, which may be far from the reality. The demand for increasing accurate scientific computations of complex phenomena and for realistic visual simulations is growing fast. Applications in the industrial and service sector require new approaches to handle the need for improved accuracy, since in many cases wrong results may have serious consequences. This is especially important in aerospace, biomedical and other areas, where accuracy is linked to achieving the goal, safety and thus cannot be compromised. Developers of applications ranging from computational fluid dynamics in aeronautics to urban transportation systems are all driven by the need to improve physical accuracy of their simulations. In principle, the simulation must faithfully capture the underlying physical phenomena. In practice, however, high quality physical models are usually approximated to improve the speed of the simulation. A huge mismatch has been developed between coarse simulations that run in real-time and those that are sufficiently accurate to model real systems, but require a considerable computational effort and thus run off-line. Rectifying this situation is an important task that requires some new thinking in the area of modelling, computations and use of the current computer capabilities.

Simulation applications generally fall into the following main classes according to their purpose, science and engineering, prediction capabilities, graphics, and link of model with the real system:

- Scientific Simulations.
- Graphic Simulations, Virtual Reality.
- Prediction Simulations.
- Emulations.
- System Integrated Simulators.

Between these classes, the requirements for physical accuracy, speed and purpose of the simulation task may be quite different. Scientific Simulations, as for computational fluid dynamics (CFD) research and engineering, demand the ultimate in accuracy and precision, and because physical accuracy comes at the price of speed, these simulations frequently run on large computers and supercomputers. On the other hand, Graphic Simulations, which include games and other entertainment media, require only that the visual result to be convincing. A great variety of clever, but disparate methods have been developed to generate physically-plausible simulations of complex objects, such as clouds, fabrics, plants, motion of animals etc. Filling the range between graphics and science, the Prediction–type Simulations comprise a vast spectrum of important industrial environmental, societal etc applications that require some degree of accuracy plus real-time, or even accelerated-time, performance and ideally should run on a PC (laptop). Emulations emerge in many fields, when the main simulation is of the Scientific type, but part of the simulator is a subsystem of the reality (flight simulators, where the cockpit and its instrumentation are parts of real system); in such cases we have an interplay between model and reality. Simulators of a scientific type with graphical capabilities may be part of a control system that receives real signals from the system, identifies the changing parameters of a structured model and implements control actions; this is a typical case of a computer control system with learning and simulating capabilities.

Clearly, a successful Graphical Simulation should be based on some appropriate approximation of the detailed dynamic responses predicted from a Scientific Simulation. This requires new methodologies for deriving simplified models from the detailed responses, capabilities for computing on inaccurate models and techniques to balance speed of computations with acceptable accuracy of results. Emulations and System Integrated Simulators are tailored to specific applications and there is general methodology for their design. The large number of emerging challenging applications requires significant developments in all above fields.

5. Emerging Applications Fields

Modelling and Simulation have been areas with a lot of activity for many years. New fields where Modelling and Simulation emerge as important activities are:

- *Modelling of the living:* The 'living' extends from the molecular level to the ecosystem. This activity involves a reconsideration of issues of *Autonomy* and *Organisation* and frequently involves the use of multi-level hierarchical models, or forms characterised by autonomy. Molecules aggregate and form networks (metabolic or other regulatory networks), they then make up cells, which in turn aggregate into higher level structures with a specific function. After the first step of characterising genes, there is now need to elucidate their interactions and the regulatory mechanisms which enable their functioning. One goal is a computer-based model of the cell and biological processes. The study of networks at the micro level is a new dimension to the macro level network theory that has provided the basis for the development of electrical applications and technology. Problems of *Synthesis* in the micro level are pivotal for chemistry, genetics, micro-systems, medical applications.

- *Social Simulations:* The micro, biology-genetics based processes have their counterpart at the higher level when behaviour of individuals, animals, or populations is considered. Simulating detailed interactions among individuals in the population, generating related complex system measurements for millions of interacting individuals, modelling spread and changes of disease processes, developing control strategies for isolation of disease, describing group behaviour of insects, animals etc are challenging new areas requiring formal modelling and simulation techniques. These are very challenging problem areas and the results may provide useful paradigms that may stimulate new technological developments. The required research has to go beyond the simple prediction studies and structural models providing a better and deeper structural understanding of the relevant distributed dynamical system. This for instance should include a much deeper understanding of how a disease interacts with its dynamical host systems etc. Biology-Social studies provide new paradigms for development of the theory of *Complex Systems* and inspire new computational approaches and forms for organisation.

- *Modelling systems with "humans-in-the-loop":* The role of humans as part of technological processes has been a subject under consideration for many years. The subject however is still open, especially, when the role of human and the machine is strong. This family of problems can be distinguished by the degree to which the human-physical/technological system interact. We may thus distinguish the strongly coupled man/machine systems (human operators etc), the highly structured interactions (financial transactions, human organisations, etc) and to less structured interactions (highway transportation, social networks). The "autonomy" of the human being is a factor that makes modelling and simulation a hard and challenging issue.

- *Modelling of Integrated Processes:* Large systems, made up of many and diverse nature sub-processes, exhibit behaviour that is complex and of hybrid nature (telecommunication networks, energy networks, systems of satellites, supply chains, etc). The modelling and simulation of such systems is still an open issue, especially under the conditions where such systems evolve through their lifecycle and when aggregate behaviours are needed with different degree of accuracy and model granularity. Systems integration is an issue that requires the linking of models, simulations of a given system corresponding to different time scales and granularity. Such developments have a number of implications for areas such computing, where the need for "approximate computations" on models with uncertainty is a key issue.

- *Modelling and Simulation of New Technological Processes:* Micro and Nano Technology have progressed considerably as far as development of devices. The next step involves going from the unit to the designed composite process with prescribed functionalities and this requires a modelling and analysis methodology (similar to that provided by electric network theory). Similar needs emerge in the field of development of new drugs with prescribed properties etc.

6. Research Needs and Challenges

The development of the field of complex systems requires experiments to establish facts, theory to interpret facts and frame testable hypotheses and finally computation to re-connect theory to experiment. The overall objective of the research for the future is to stimulate a vigorous examination of the capabilities required for scientific analysis of complex phenomena. This will lead to a better understanding of new ideas and approaches to complex system modelling, which can serve to guide research activities in modelling and simulation of complex systems, and contribute to the development of more powerful simulation tools suitable for the nature of the applications under consideration. Some of the specific generic problems, which emerge in this area of research and which are linked to this framework come from real-world systems, biological, physical, social to artificial systems like software systems or systems in nano-technology composed of many components. A list of challenging areas requires development of the modelling and simulation tools are:

- ***Organisational Structures, Hierarchies and multi-scale modelling*:** The Information-Measurement and Control structures of systems are subject to forms of organisation. Organisations usually are the products of evolution and thus they emerge without been considered as products of a design process. The needs for flexibility of operations frequently requires the re-engineering of organisational structures. Organisational structures are usually imposed on composite systems. Methods for building an understanding of full system performance from knowledge of sub-system behaviour and under the presence of a given measurement-control structure is critical. A description of systems at different levels of a hierarchy (see Figure (1)) will be necessary to ensure that simulation tools are scalable, and able to handle the large systems that science and technology must deal with. Hierarchies involve in a natural way multi-scale and variable-granularity processes. A typical example of such processes is the multi-layer hierarchy of operations of industrial systems, which may be extended to include logistics, business processes and enterprise issues. Multi-scale problems include at least systems with multiple length scales (e.g. atoms, molecules, parts) or multiple time scales (e.g. short term chemical reaction vs. long term whether phenomena), or viewing the same dynamic process from different perspectives (quality, safety, risk issues on dynamic processes). A system ontology ranging from the micro-level of interacting entities over intermediary meso-levels of (spatio-temporal) structures to macro-level where lower level structures become entities in themselves could lead to a new framework of modelling.
Application Areas: Operational issues of the technical and Business type of the Integrated Industrial Enterprise, Management Problems, Business Re-engineering, Supply chain management, Biological processes etc.

- ***Data acquisition and accuracy of prediction*:** A major open issue is the understanding and handling of the transition from data / information / knowledge. The whole issue of how to analyse complex systems is still an open thing. Pattern finding is part of that and also includes the key problem of reconstruction of models from incomplete data. In fact, in analysing complex systems, the data problem is critical and contains two extreme forms: too much and too little. Weather satellites and genomic methods produce vast amounts of data, but in other cases there is sparse data about full system performance. In both situations, one needs more powerful methods for extracting the most information out of the available data. We require techniques that would enable us the setting up of appropriate experiments for identification, generation of relevant data and which may facilitate modelling and simulation especially of systems for which there is at present insufficient direct knowledge. A major open issue is the understanding and handling of the transition from data / information / knowledge. The whole issue of how to analyse complex systems is still an open thing. Pattern finding is part of that and also includes the key problem of reconstruction of models from incomplete data. Methods for determining the levels of accuracy and limits of applicability of simulation results must be developed. Attention is also needed to the problem of missing, or incomplete data and we can overcome such difficulties. It would be challenging to have simulation of systems with incomplete data. This is particularly important when simulations are used to support high impact decisions, for which the cost of a mistake can be very high. Areas such as systems identification, Design of Experiments, Pattern Recognition, Machine Vision, Bio-Inspired Computing etc have a significant role to play in the development of the required new methods.
Application Areas: Such systems occur especially in ecology, molecular biology, certain technological-information processes (internet, etc), systems with the human in the loop (management, finance, economics) and in human medicine.

- ***Model Embedding:*** For a given system, families of models may be extracted by model reduction of the representation, simplification and/or extraction of dynamic features, or some general form of aggregation within an organisational structure. Simulation tools developed for each of the clusters of the simplified models are usually not interlinked. Integrating such tools requires understanding the partial ordering between families of

simplified models (variable model complexity) as well as the relationships between the models in the chain, which are extracted from a common physical system. Model embedding implies understanding of the links between the families of models and being able to explain the effects of the different length scales and different granularities in the different types of simulation. The relation between the structure and its interaction with the dynamic potentialities is very important and it is probably a more fundamental point of research in the *Model Embedding* problem. This implies going from topology to dynamics and next from dynamics to functionality. Such developments require also research in mathematical areas. This area requires the development of concepts and tools which also explain the "bottom up" and the "top down" viewpoints when we move in hierarchies. Transformation of structure, aggregation of parameters and the role of boundaries are further issues to consider when going from finer to coarser or coarser to smaller.
Application Areas: Operational issues of the technical and Business type of the Integrated Industrial Enterprise, Early/Late Design of Engineering Processes Evolution, Engineering Re-design technological processes, Re-design of Supply Chains, Growth of Network Systems.

- ***Modularity of Systems:*** The study of Large Scale systems requires methodologies that reduce the complexity of the overall problem by reducing it to smaller dimension problems of manageable size. Very frequently we deal with systems that can be naturally seen to be composed of modules. The definition of modular structure and decomposition of a system may be a convenient tool to describe, model and simulate complex systems and it is adopted in the study of large dimension processes. Such decompositions however force us to consider interactions between modules as disturbances and make the design process dependent on the specific sequence that is used in design. Modelling and Simulation tools for understanding the problem of *Sequencing of Design* are essential tools for such studies. Procedures for defining the modules (probably relating to functionality) and addressing issues of sequencing of the design process are challenging topics.

Application Areas: Large Scale Chemical Process Systems, Energy Systems, Transportation, etc.

- ***Structure Evolving Systems:*** A major class of challenges of new challenges in the field of technological processes are those linked to the new paradigm of *Structure Evolving Systems (SES)* which departs considerably from the traditional assumption that the system is fixed. The dominant features of this class are:
  - The topology of interconnections is not fixed but may vary through the life-cycle of the system, or vary due to discrete events, or may vary randomly.
  - The overall form of the system may evolve through the early-late stages of the design process
  - The considered system is frequently a "System of Systems" and thus there may be Variability and/or uncertainty on the system's environment during the lifecycle.
  - There may be variability in the Organisational Structures of the information and decision making (control) in response to changes in goals and operational requirements
  - The sub-processes (units) may vary during the life-cycle of the system.

The overall framework here is influenced by the genetic mechanism in biology. The development of a generic methodology, based on a suitable conceptual framework and supported by analysis and synthesis tools is importance and can be beneficial to other domains. Such developments are influenced by notions of evolution from Biology, Genetics, Crystallography; however, the backbone is provided by Mathematical Modelling and Systems Theory, Control Theory, Measurement, Organisation Theory, Information Theory, Mathematics and Computing/Computer Science. In the case of Biology and Genetics the problem of structure evolution has its special difficulties. In fact, they are hard problems to simulate since structure is constantly changing / adapting.
Application Areas: Specific paradigms include: Integration of Early-Late stages of Engineering Design. Integrating Operations in Industrial Enterprises and their linking to Business. Control of Communication/ Traffic Networks. Control of Large Scale Power Systems under Market Deregulation. Design of Flexible Space Structures. Design of Supply Chains. Re-engineering of Technological and Business Processes. Databases and Information Systems.

- ***Emergence and the "system of systems" problem:*** The central notion in the concept of the system is that the whole has properties different than the aggregate of the parts. Predicting the emerging properties as a function of those defined on the subsystem and the interconnection topology is an ongoing field of key study in systems theory. The study of *emergence* has taken special attention due to that we are now consider systems at the micro-, nano-level (micro systems, nano systems, genetics etc) or macro-level (organisations, population dynamics, supply chain networks, communication networks) where the local properties and interconnection topology are not themselves capable in predicting the emergent properties. In fact, the evolution of emerging properties goes frequently beyond nonlinearity related phenomena. Systems interacting through their connection may be structurally affected by their local environment. Such problems emerge in the consideration of systems evolved as the organisation of other systems, referred to as *"system of systems".* The modelling and simulation of such systems are prerequisites to studying emergence and major challenges come from the complexity of structural interactions between subsystems, large dimensions, uncertainty in the description of subsystems etc.

Application Areas: Specific paradigms include: Integration of Early-Late stages of Engineering Design. Integrated Operations of Industrial Systems. Micro-, Nano-Systems. Communication/ Traffic Networks. Large Scale Power Systems under Market Deregulation. Evolution of Supply Chains. Company merging. Integrating Databases and Information Systems.

- ***Graphical-Detailed and Hybrid Simulations:*** This addresses the study of relations between detailed scientific and approximate dynamical simulations based on GPU technology. The derivation of approximate simulations on the basis of the detailed ones implies study of new forms of model simplification. This area of work requires also developments in the area of "rough", or "approximate" computations. The issue of event driven discrete/stochastic simulations versus continuous simulations is still open and needs special attention. Such hybrid simulations can appear at different levels of a multi-scale modelled process; it may happen that a discrete simulation discovers effects that can not be found with a continuous one and vice versa and frequently we might have to resort to hybrid due to the integration of models with different characteristics. The essence of hybrid simulation is the ability to integrate models and simulation tools for mixed type systems characterised by dynamics of different nature.

Application Areas: Large Scale Chemical Process Systems, Energy Systems, Transportation, Air Traffic Control, Management etc.

- ***Uncertainty and Validation:*** The problem of incomplete data leads us to the problem of validation of results. It is clear that wherever possible experiments need to backup any simulation. There are however, a variety of fields (climate research, toxic chemical reactions, radioactive decay…) where experiments might be too dangerous, difficult or impossible to organise, or very expensive. For these fields we may have to find a reasonable way to validate the results. This implies combination of simulated results with other data, possibly obtained by history of observations etc. A key issue is to deal with the uncertainty of data – both of those retrieved from simulation and those retrieved from other sources. The inherent uncertainty in models implies that it is meaningless to work with accuracy in computations greater than that of the model. The development of modelling and simulation tools for problems with inherent parameter and possibly structural uncertainty requires ability to perform *approximate*, or *robust computations* on models with parametric uncertainty. Such issues should be properly addressed since a lot of the general issues considered so far rely on them.

Application Areas: Engineering and non-engineering problems.

- ***Supporting Research Activities:*** The development of the challenging new fields in the area of Modelling and Simulation assumes that additional developments take place in fundamental research areas, the results of which are crucial for significant developments to take place. Amongst those areas which need special attention are:

    - *Stochastic Modelling and Reliability :* Our knowledge of essential features of complex systems is usually incomplete, leading to the need for a probabilistic description and handling uncertainty. New powerful methods for treating stochastic dynamics, System Reliability and evaluation of Risk are required.

    - *Algorithms, Software and its Integration*: Computer science must develop to contribute powerful, algorithms that are able to handle systems with many interacting components, provide better solutions to software modularity and (standardised) interfaces. Progress in the field of software integration is important.

    - *General Architecture of Complex Systems and Description of Systems via Formal Methods:* This approach is attempted e.g. in areas like system biology where attempts are made for formal descriptions of the molecular processes and they are better suited to the needs of system biology science. Such methods are supposed to supplement kinetic models that take a purely biochemical approach. Transferring these results to other domains will be beneficial.

- *Network Theory and Dynamics*: Traditional Network Theory has developed on the basis of electrical components and interconnection topology. Today we are concerned with many different forms of netweorks. Complex networks arise in the analysis of gene regulation, metabolism, the operation of electric power grids, social systems, and many other problems. Analysis of dynamics and the flow of information on such networks has emerged as an important part of complex system modelling.

- *Data Modelling:* Development of an approach to describe the “life”, “transformations” of data in Databases is an issue that requires attention. This is of special importance for integration of families of models corresponding to a hierarchical organisation and supporting many other activities.

7. General Aspects: Impact on Competitiveness, Environment and Society

The field of Modelling and Simulation has influenced the general technological developments in the last half of this century considerably. Furthermore, such tools supported also by a general Systems framework and the appropriate Measurement and Control-Decision Making tools have been accepted by many disciplines outside engineering and its applications. There is a considerable gap, however, between the level of theoretical developments and their applicability; however, such gap is not uniform across the different application areas. Aerospace, Defence, Electrical and Electronic sectors are in the forefront of taking up of advanced methodologies and tools. The areas of Mechanical and Production engineering has also witnessed recently a significant taking up of results from the field of Discrete Events modelling and simulation, whereas advanced control concepts and results have influenced the development of the Mechantronics, Robotics applications and have contributed in the introduction of Automation in many production areas. Chemical engineering has been one of the first areas to use Modelling, Simulation, Diagnostics and Control results, but it has been rather conservative, as far as adoption of advanced techniques and results in the area of Control; it is only recently that there are signs of use of advanced methodologies there. From an engineering perspective, man-made systems are increasingly complicated and system design is at the edge of a complexity barrier and we will soon need novel methods how we can scale-up systems while still keep them maintainable and reliable. Meeting these diverse needs will strongly influence the course of science in the coming decades. The field of applications where engineering type methodologies and solutions are required has increased dramatically in the last twenty years. The development of E-Commerce is a typical case that has opened-up the field of applications. New forms of engineering are needed requiring new methodologies based on advanced Modelling and Simulation methods and tools.

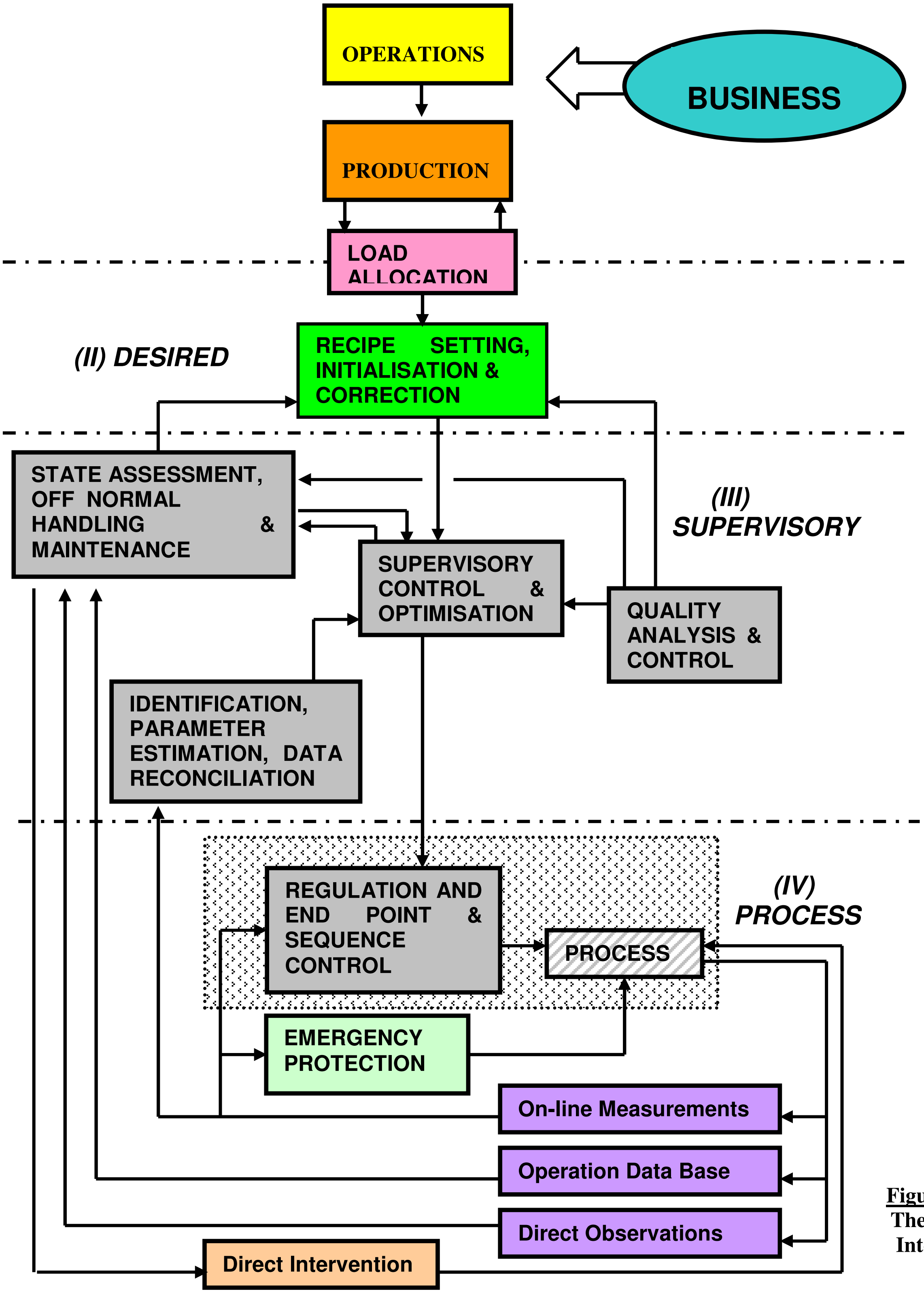
As far as increasing the taking up of advanced concepts, methodologies and tools from the Modelling, Systems and Simulation areas, the problems are different in the different sectors. In the traditional engineering areas the main obstacle is the evaluation of benefits derived from use of advanced methodologies in areas such as enhanced performance, profitability, safety, protection of the environment, improved control of the manufacturing process etc. An alternative factor affecting this process is the general economic climate. In the non-traditional applications areas the problem of using Modelling, Systems, Simulation and Control ideas is of different nature. Identifying the Systems, Modelling and Control aspects, formulating the appropriate problems to solve in this new set-up, defining the simulation requirements of the specific application and establishing a common systemic language, define some of the major challenges. Such tasks become quite challenging, especially in interdisciplinary nature projects. Improving the taking up of advanced concepts and tools requires:

- Research and Pilot studies for quantifying the relative benefit of use of advanced methodologies.
- Development of the Modelling, Simulation, System and Control for problems of interdisciplinary nature.
- Development of education and training programmes in the areas of Systems, Modelling and Control emphasising the significance of the field in both traditional application areas and interdisciplinary work.
- A closer co-operation of fundamental Scientific disciplines and Engineering is essential, if the development of the emerging new forms of Engineering, is to successfully address the current needs. This is critical for the development of the required new educational initiatives.

8. Conclusions

In recent years we have witnessed the need for engineering type solutions to a variety of non-engineering applications, such as Business, Finance and Commence, Integrated Operations and Management of Industrial Processes, Environment, Transport, Risk Analysis, Medical Applications, Information Systems etc. Electronic Commerce has increased the range of applications and development and Decision Making requires new Modelling Tools. Responding to such challenges requires the development of some new form of general engineering, which can cope with the interdisciplinary requirements. A distinct feature of this new form of engineering is the ability to model complex problems originating from different areas, carry out analysis and develop relevant solutions. Modelling and Simulation provide the cornerstone for such developments. The recent scientific developments in areas such as Biology, Genetics, Medical Applications, Quantum Electronics and Computing etc has opened up the areas where Modelling and Simulation are needed. The general cluster of new challenges is frequently referred to as *Complex Systems.* Modelling complex systems is a profound challenge, driven by societal needs and scientific opportunities. Revolutionary methods of data acquisition are providing immense amounts of information in fields such as molecular biology and more powerful means of exploiting this information are needed. Modelling is critical in advancing our understanding of living systems, as well as enhancing our ability to intervene by designing effective therapeutics for them. In social systems, scientific assessments are needed to inform decisions about inherently complex matters such as national security, public health, deployment of new technologies and enhancing the understanding of the impact of technology and development on the environment.

Modelling and Simulation underpin all activities in handing the new challenges we are facing at the moment. They are critical for the development of new forms of technology, understanding and managing the challenges in the Biology-Genetics area, developing new initiatives in the Medical field, managing energy and understanding better our impact on the environment. Modelling is the common basis to human activities and thus its development is also a measure of our ability to understand nature, society and related issues.



<u>Figure (1):</u>
The Functions of the Integrated Process