Development Paper

LeanOptimal

LeanOptimal Summary

Lean Optimal addresses a critical barrier to manufacturing enterprises in all sectors including automotive, aerospace, shipping, and their value chains successfully meeting the challenges arising from 'the uncertainties of continuously and rapidly-changing market conditions and increasingly shorter time-to-market requirements'. Meeting these challenges requires predicting and managing successfully the increasing levels of internal process, product, and supply and demand variability arising from these market factors.

The presence of variability adversely effects process quality and reliability, which themselves then disrupt operational plans for supply, production and distribution. The use of the plethora of existing quality and planning control practices are futile since any plans produced quickly become obsolete. Optimising process capability and competence under these variability conditions is the key to successfully meeting the challenges. Lean Optimal, therefore, focuses on addressing the variability issues that ensure complex manufacturing value chains are able to optimise process competence and achieve efficient demand driven manufacturing in high product variety, low demand volume, low cost and high quality market environments. This is achieved by developing an autonomous and intelligent approach to process optimisation through use of highly responsive system combined with the use of intelligent algorithms to ensure effective optimisation. The autonomous system, through its detailed control networks, will enable rapid responses to changing product, process and demand uncertainty and change. Lean Optimal by providing means of managing the sources, levels and effects of variability will overcome the uncertainties problems.

The focus on lean based process optimisation will create an opportunity to optimise the cost, quality and delivery performance and the intended ICT solutions will enable enterprise-wide lean practices to be adopted by an increasing number of small manufacturing enterprises.

Objectives of Lean Optimal Concept

The objectives of Lean 'Processed-based' Optimal (Lean Optimal) are to develop a cloud base autonomous and intelligent, self-optimising and adaptive system that:

- **i.** continuously monitors the efficiency of resource utilisation, quality and effectiveness of a large number of processes and then later extend this ability to the associated supply chain processes,
- **ii.** provides early warning signals when process and product variability begin to adversely affect the process capabilities,
- **iii.** identifies potential links between 'out-of-control' process capabilities, including under and over production,
- **iv.** predicts when the capabilities of processes are likely to become 'out-of-control', and
- **v.** makes decisions on how to improve the process and bring it back under control by triggering the most appropriate and cost-effective 6-sigma interventions.

In order to achieve these objectives Lean Optimal requires the introduction of automation mechanisms including novel software tools enabling:

i. *the monitoring of process capability* through the introduction of a measurement information system based on a novel lean 6-sigma Key Performance Indicators (KPIs). The data management and collection of such a system must be adaptive in the sense that it can, for example, alter the sampling frequency or size based changing environmental conditions. The ability to collect data from a range of database applications, such as ERP and shop floor data collection devices will also need to be catered for,

ii. *early warning detection,* by dynamically generating statistically-based control limits, from the automatically collected data for novel Lean 6-Sigma PMs, monitoring PM values and providing alerts when 'out-of-control' conditions become likely to occur.

iii. *causal analysis and reasoning,* through the introduction of advanced Neural Network-based and Artificial Intelligence applications. These applications will be able to simultaneously analyse the multitude of 'out-of-tolerance' conditions and then generate a probabilistic graph of causes and effects that will be used for assessing and predicting the likelihood of 'out-of-control' situations.

iv. *self-configuration of an autonomous and intelligent functionality* that integrates the physical, information, sensor and computing resources of a manufacturing value chain into a single cyber-physical system that is capable of undertaking autonomous and intelligent process optimisation decision-making throughout the value chain and to link with A&I systems currently being developed under UK TSB funding, using the same application principles, for finite capacity planning, demand management and process competence improvement. A&I system configuration should be specifically for an individual manufacturing value chain. In order to achieve this the project objectives are that to self-configure the software tool should be able: (i) to automatically collect details of the 'part-lists' that will form the basic physical components of the autonomous system; (ii) to automatically collect the metrics used to measure the performance of physical components; (iii) to automatically identify the topologies, network-based configurations, which make up the structural relationships between physical components and activities; (iv) to automatically develop local-level logic that controls the activities that physical resources contribute to; (v) to automatically develop sub-system and whole-system logic that controls higher level activity and system behaviours; (vi) to automatically identify opportunities for the application of optimisation algorithms and select, configure and use these algorithms. Upon configuration the A&I system configured software tool should be able: (i) identify and undertake autonomously and intelligently process optimisation at a machine and process levels; (ii) identify and undertake autonomously and intelligently process optimisation at a msub-system, whole-system and value chain node levels; identify and undertake autonomously and intelligently process optimisation at whole value chain levels.

The intention is to devise an EU project with a view to promote Lean Optimal concept. The objectives of the project will be:

i. Clear in that they are aimed at developing a technical demonstrator with specific A&I-based process optimisation capability that can be added to current industrial user partner manufacturing ICT systems.

ii. Measurable in that the resulting demonstrator will be applied to industrial partners' systems and the outputs of demonstrator and validation trials measured using quantitative performance metric that include delivery response times, due date improvements and increased numbers of product types coped with.

iii. Realistic in that the A&I approach to be adopted is based on recent and current research projects funded through the UK Technology Strategy Board which applied the underlying autonomous system development principles to three areas, i.e. autonomous finite capacity resource scheduling, autonomous demand management and autonomous model development for process improvement.

iv. Achievable within duration of project since within the consortium, the partners possess all required resources, knowledge and skills to achieve the project objectives and there is particular and considerable experience of developing within manufacturing value chains, autonomous systems, advanced knowledge collection and management systems, advanced decision-making systems, developing and using sensors and sensor networks and applying ANN and GA artificial intelligence.

v. Consistent with the expected exploitation and impact of the project in that the project partnership contains members across the whole value chain and those who have experience and skills in project management, dissemination, product commercialisation and marketing products and gaining, managing and recording of research impacts.

Concept and approach

The underlying principles of the autonomous systems functionality within Lean Optimal arise from a trans-disciplinary research project, funded by the UK EPSRC, in which discrete event simulation modelling was developed to enable the autonomous nature of the processes involved in the regulatory control of biological gene transcription to be examined in detail. These control processes enable complex networks of control-proteins to transcribe structural-proteins in the right quantities, sequence and time to ensure that whole organisms can autonomously maintain homeodynamic equilibrium. When applied to a manufacturing such 'autonomous' equilibrium involves the ability, of all work systems within an organisation, to constantly adapt their internal environments to the growth, development, activity and ageing of the organisation that the work systems forms part of. It also involves maintaining working efficiency and effectiveness whilst the organisation is challenged by episodic and/or systemic chaos in its environment, i.e. the specific challenges to be addressed through this 'Process optimisation of manufacturing assets' call.

Through comparisons of GTRN-based control and control processes within manufacturing environments this biological modelling approach was adapted for use in manufacturing. Here significant inventive steps, produced insights concerning the nature of proteins constituting the GTRCN 'parts lists' and their use to represent the physical components and control metrics used within manufacturing functions, i.e. (i) physical resources such as machines, materials and operators, and (ii) the performance metrics such as work-in-progress levels. There are no existing systems capable of this level of technical innovation and it represents a significant step forward in terms of the scientific principles underlying autonomous systems. The basic components that make up the GTRCN-based approach to autonomous systems design are listed in Table 1:

1. Part-lists which contain bill-of-material based lists of: (i) the basic activities, (processing, manufacturing, packaging and distribution), involved at each stage in the supply chain, (ii) the material, equipment, personnel and information resources required for undertaking individual activities, (iii) the basic features of each resource that are used to undertake each activity and that control levels of flexibility, and (iv) the performance metrics used to measure the flexibility, cost, quality, delivery and sustainability of process-activities.

2. Control topologies which are the network-based configurations that represent the sequential and concurrent precedence relationships between the performance metrics of resources and activities and activity-activity groups.

3. Local level control logic at each network node which represent cause-and-effect relationships between resource performance metrics.

4. System level control logic again positioned at nodes that measure and control supply-chain level behaviours within their networks.

Table 1: Autonomous System Components

Our existing perspective has focussed on the need to add autonomous planning functionality to existing complex decision-making areas of manufacturing and is based on using the Schlitt and Brazma approach, (Schlitt, T. and Brazma, A., 2007, “Current approaches to gene regulatory network modelling”, BMC Bioinformatics B (Suppl 6):59, pp 1 to 22), of modelling GTRCNs at different scales and building application components at varying decision levels based on real operational and process needs.

The GTRCN approach provides a generic method of building autonomous systems across a wide range of manufacturing sectors and across a wide range of manufacturing processes and order to significantly exp increase the levels of sophistication, planning and control functions. It is particularly appropriate to building autonomous systems functionality in the complex working environments within project partner’s enterprises.

Of significant interest are the GTRCNs involved in hormonal processes that enable large numbers of cells within the body to respond collectively and appropriately to varying stimuli and the innate and adaptive immune responses that can anticipate and eliminate harmful activities. Furthermore, GTRCNs control biological processes at many functional levels that range from the expression of individual genes, through many hierarchical levels of sub-system levels through to hormonal GTRNs that exercise control at whole body levels. The manufacturing-based autonomous control principles derived from GTRCNs, and further adapted and developed within the Lean Optimal project, will have the same capabilities. They will enable responsive decision-making and optimisation processes to operate at manufacturing process, sub-system, whole system and value chain levels. They will, therefore, enable synchronisation and control, through use of performance metrics, of the basic activities undertaken within a manufacturing environment at individual process operation levels, whole process levels, process group level (batch and flow processing), whole factory level and whole value chain levels. This will provide the responsive and high quality decision-making and process capability to reinforce capacity to manufacture high-quality and innovative products and to penetrate new application areas. The autonomous logic to be developed will enable faster reaction to internal and external changes affecting individual processes, sub-systems and whole system. For example sudden changes in demand volumes between products can be reacted to automatically through the control logic reallocating material, equipment and personnel resources along the value chain. The autonomous systems to be developed through Lean Optimal will hence provide a paradigm increase in capability for better and faster reaction to market changes by being able to use holistic global and local optimization algorithms in a collaborative value chain. The use of GTRCN principles also enables autonomous systems to be built for individual manufacturing areas and/or functions and for control integration and synchronisation to take place between these areas/functions, i.e. an interoperable de-centralised architecture approach. Reduced complexity of production systems, by at least an order of magnitude, is then possible with higher level control network providing and interoperability frameworks.

The novel artificial neural network technology used to identify emerging process cost, quality and delivery issues and to provide temporal-based predictions of process reliability, capability and efficiency.

The development and introduction of novel AI-based neural networks by several partners in the consortium (Ziarati, 2009; Urkmez, 2009; Akdemir, 2009) has enabled the parallel processing of a large number of variables and high volumes of data. This computational breakthrough will enable continuously monitoring of processes by analysing its performance metrics and variables and predicting which processes or parts of the processes may go out-of-control. The range of AI modelling will enable various configurations and topologies to be analysed and blended in order to devise a novel and optimised ANN architectures. Figure 1 shows the recently developed 3-dimensional neural network system (Ziarati and Bilgili, Ucan Nuri, 2009; Ziarati, et al, 2013) with a capability of handing 2-dimensional problems/scenarios in real-time or 3-dimensional problems.

The various advances in the AI technology, ANN and CNN will enable the following:

a) *Improvement of prediction accuracy of process failures*. The project can specifically address the application of ANN and CNN and the associated training features including the role of Generic Algorithm (GA) in the CNN training and testing. This will be carried out with C4FF and PRU as well as ATB. This review will lead to a greater understanding of how relationships are established within NNs and how these relationships could be improved. Gas are proven evolutionary computing optimisation techniques modelled as a metaphor of the biological notions of genetics and natural selection. Their probabilistic approach to searching large spaces will be used to train the CNN and to inform on ANN modelling procedures as well as the model forecasting relationships with the aim of improving prediction accuracy of process failures and, therefore, reducing the probability of false alarms or late detections.

b) *Minimisation of uncertainty in the forecasting process.* By definition a forecasting is an estimation exercise and uncertainty is an inherent characteristic to any estimation or forecasting process. The review of Fuzzy Logic (FL) applications in ANN and CNN will allow for modelling fuzzy areas where tolerances can be set/re-set for changing performance metrics, and therefore for representing uncertainty. This will allow modelling and measurement of estimating imprecision and uncertainty related to process failures. Based on the obtained measures a 'de-fuzzication' process can be performed on the fuzzy areas by order of importance. Here, C4FF have developed tolerance bands for processes to allow for the system to be fault-tolerant.

c) *Automatic Modification of Sampling Frequencies*. These can occur in-line with changes in process performance. Data from processes are collected on a continuous basis and if near out-of-control cases are noted then sampling frequencies will be modified and a closer observation put in place. The probability that the process may lead to a failure, based on set metrics, will trigger a review of the resources on the shop-floor and re-arrangements of the process configuration to optimise the flow and minimise bottlenecks in the system. C4FF possess a high level of application knowledge of ANNs, and PRU and C4FF have many years of research experience in CNN. Within the partnership there is a high level of experience in Gas which will form the backbone for neural network selection and development of the Lean Optimal techniques.

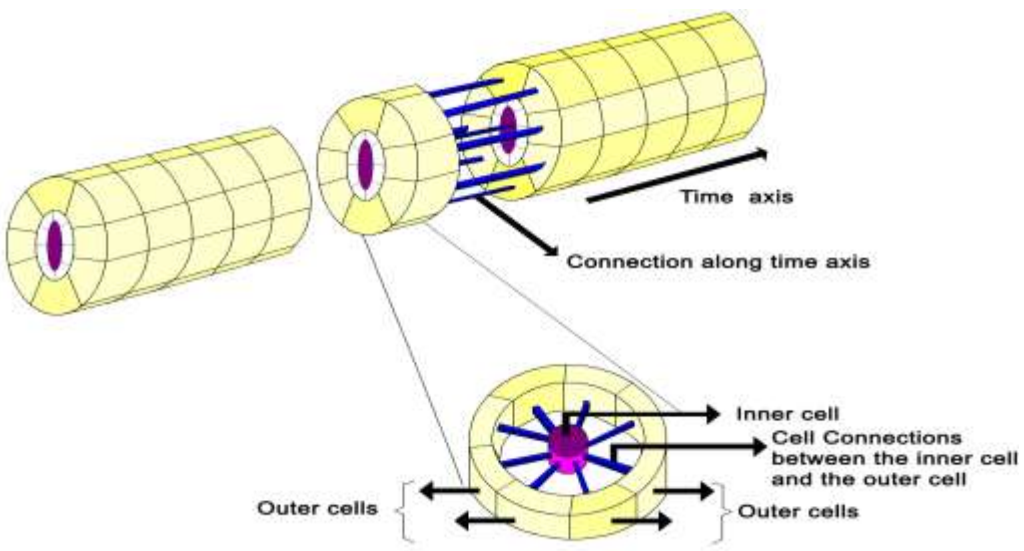

Figure 1: 3-Dimensional CNN Architecture – (Source, Ziarati and Bilgili, 2010)

Novel knowledge management processes used to extract intelligence from large sets of process and value chain data.

An aim of Lean Optimal is to design an advanced data and knowledge management system, see figure below for structural details, that has the ability to manipulate various types of data and heterogeneous data sources. Lean Optimal will particularly allow data to be smoothly integrated from:

i. a large number of processes by monitoring each process on the shop-floor to detect changes in the operating variables and related performance metrics and assess if these metrics are going out of the pre-defined tolerance ranges. This will include the optimisation of production scheduling.
ii. external data sources (e.g. the World Wide Web) and extracting for similar processes applicable metrics defined by competitors,
iii. demand and sales process data, to track variance between demand forecast and sale actuals.
iv. The intention is therefore to introduce a novel technology and a new approach for gathering and managing data and knowledge, searching for available knowledge and extracting intelligence.

The system developed as part of the TSB (Ifor, 2010) will be incorporated into the Lean Optimal as shown in Figure 2.

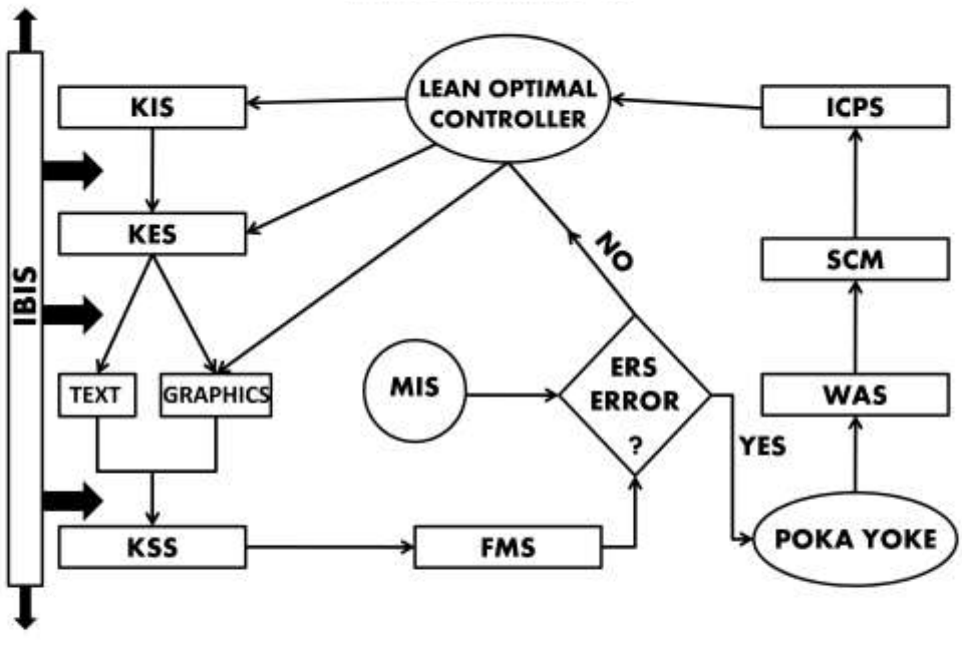

Figure 2: Structure of the knowledge management process
(Lean Optimal Sub System/Software: - Based on the outcome of a recent UK's TSB project.0

Key to terms in Figure 2

- Knowledge Identification System (KIS)
- Knowledge Extraction and collection System (KES)
- Knowledge Streaming and analysis System (KSS)
- Forecasting Models (FMS) - ANN vs CNN
- Poka Yoke (PY) – Based on C4FF RZ Charts
- Error Reader System (ERS) – Error indicates out-of-control/failure prediction
- Warning/alerts and Action System (WAS)
- Sudden Changes Manager (SCM)
- Inventory Correction and Planning System (ICPS)
- Manual Intervention system (MIS)
- Lean Optimal Controller - Receives information from ICPS and transmits the information to KIS, KES in graphical form. KIS and KES will be linked to companies ERP System or an open ERP or IBIS developed by C4FF.