

# Man-Machine Interaction Model for Occupational Risk Modelling

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**Abstract.** This paper defines the MORM Model (Man-Machine Occupational Risk Modelling) which is devised for modeling risk in wide-scaled industrial systems. We introduce the basic principles of the Human-Machine interaction model based on a dynamic approach on one hand on the extended Cognitive Reliability and Error Analysis Method (extended CREAM) and on the other hand on a high level Petri Net formalism called CO-OPN (Concurrent Object-Oriented Petri Nets). To illustrate the MORM Model we adapted a case study of a metal wire making process.

## 1 Introduction

Nowadays, systems' complexity increases (size, component number, ramification, automation level,...) in the industry while protection of workers is more demanding. Production systems are higher priced and more specific so that more dangerous since there's not enough statistic data about their use. As a result, potential occupational accidents in such process are more acute and then less acceptable. Thus the occupational risk should be processed precociously and methodically.

The literature of Risk Analysis (RA) holds many methods [1][2] that deals with Risk management and Occupational Health and Safety (OH&S). Most of these methods are based on static evaluation of danger. Despite of these numerous RA methods, it must be emphasized that Modelling accident processes involving complex time relationships is still challenging. Recently, development of dynamic simulation tools [3], such as colored Petri nets (CPNs), have shown promising results in such modelling. This variety of methods might be System-oriented called also Process-oriented or Machine-oriented. Man oriented RA methods are generally focused on the experience of the OH&S experts, thus often not sufficient in the context of new systems. Our work's aim is to develop a model of the Human-Dynamic Process System interaction model suitable for Occupational Risk management: "Man-Machine Occupational Risk Modelling" (MORM). MORM might be

seen as "Man-Oriented Risk Analysis method" with a Process-Oriented facet since it models the Machines' system and its Environment.

In this paper we present a Human-Machine interaction model based on a dialect of Petri Nets called CO-OPN (Concurrent Object Oriented Petri Nets). We will mainly present the modelling aspects at the machine level and on the system level obtained by interconnecting elementary machine. Available analysis techniques will be suggested in order to clarify the expectation of the MORM method in terms of risk prediction. Analysis results are principally obtained by simulation of the whole system model.

## 2 MORM context

Initially developed in 'sensitive' fields, such as nuclear or chemical plant safety, systematic risk analysis methods are still mainly used to prevent major industrial risks. The Modelling concepts and the developed tools are used only at a very limited extend in the OH&S field, in which *a posteriori* analysis is prevalent.

### 2.1 Existing Risk Analysis Methods

Risk analysis methods are empirical and belong basically to three main family:

Inductive such as AMDEC (Analyse des Modes de Défaillance et d'Effets et Criticalité), HAZOP (HAZard and OPerability study) or HACCP (Hazard Analysis and Critical Control Points);

Deductive such as FTA (Fault Tree), RCA (Root Cause Analysis) that are more used in the computer-assisted RA domain;

Hybrid such as MOSAR (Méthode Organisée et Systématique d'Analyse de Risque).

Retrospective methods pose ethical problems, besides it must be emphasized that such approaches are of limited use to prevent health diseases in complex changing work-

places, such as machine, robotic tools and above all dynamic process systems.

## 2.2 Deficiencies of the existing Methods

Despite this variety of the accident theories available at this time, dynamic system Modelling is still difficult [4]. Classical Risk Analysis methods, particularly in Occupational Health and Safety, present some limitations such as single-orientation (Man or Process-Oriented), inability to simulate time constraints, and dependency on the expert judgement. Besides, being largely dependent on Man-Machine relationships, workplace hazards can not be addressed through a single-oriented approach. Moreover these methods do not provide reasonable results in Modelling accident processes involving complex time relationships.

## 2.3 Basic motivation of our approach

This last point is the main aspect where Colored Petri nets, and its variety of dynamic simulation tools have shown promising results in such Modelling. Our research work is focused on modelling the Human Machine interaction with a dynamic approach. Moreover, dynamic modeling tools based on a strong mathematical semantics can be used to predict behaviour with more accuracy.

## 3 Illustrative Example

In order to develop an example of the Man-Machine interaction model, we observed an industrial metal wire making process (Fig.1). This process consists on producing metal wires from large metal billets. Billets are ridden over a conveyor then distributed to three induction furnaces where they are heated. Once the billet reaches the right temperature, a hydraulic piston pushes the billet out of the furnace to a conveyor. this conveyor drives the billet into a hydraulic press that use it to produce the metal wires.

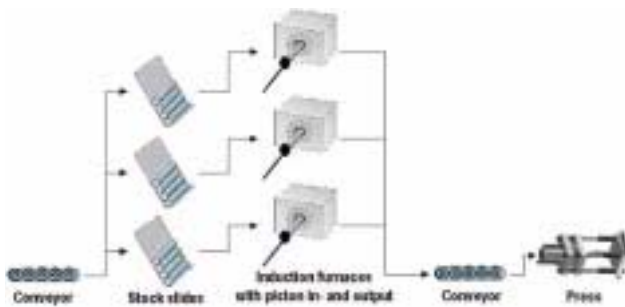


Figure 1 : Metal wire process

The control and regulation of the metal wire process are shared between an automatic controller and human operators (extracting heated billet from the furnace, starting the pressing sequence,... ).

The first problem is to build an abstract model of each component in this process. Then define how we interconnect the different components in order to get the model of the entire industrial process. So far, we translate the industrial process into a Petri Nets structures suitable to be simulated and analysed.

## 3.1 MORM Model : Machine Protocol

In this subsection we introduce the Machine Protocol (MP). A Machine Protocol (Fig.2) describes how each component (Machine) reacts with its environment out of the whole process. At a first view, a machine is a black box with inputs and outputs. The inputs are the Flows, the External Actions (correct and error) and the Used Energy whereas the outputs are the Produced Flow and Energy. Therefore each machine is considered as a set of normal and degraded states where the Man-Machine occupational risk is basically linked to the degraded states of the machine and the wrong actions of the operator. Indeed, we consider that while working, each machine might moves from one state to an other under its inputs or outputs or more under its proper influence.

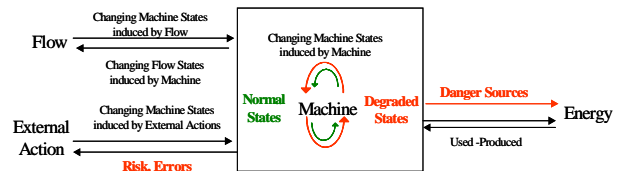


Figure 2 : Machine Protocol

The changing machine states could modify the flow states, and generate also an occupational risk while producing energy since it represents a danger source. As an example, the induction furnace states are :

Stop (ST), Standby (SB), Working (WO), Working-overheating (OV), Breakdown (BR), and Irreversible breakdown (IB). Where the three last states are representing main danger sources. We consider as an event each transition from one state to another labeled by "New state at state" e.g : Stop at Standby (where stop is the new state and standby is the previous state), Stop at Working, Irreversible breakdown at Working-overheating ... shortened by  $ST \leftarrow SB$ ,  $ST \leftarrow WO$ , ... Figure 3 gives the basic rules of the transitions of the induction furnace subject to the human External Actions.

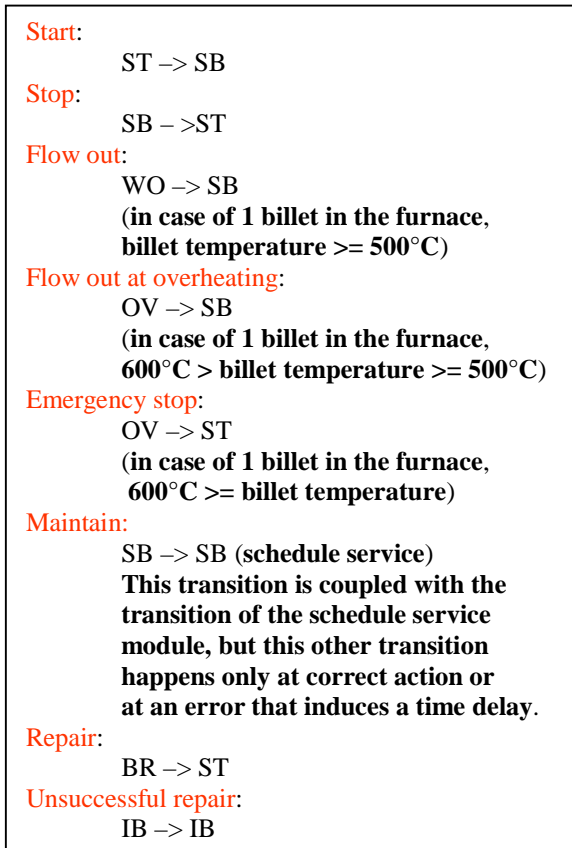


Figure 3 : behavior of induction furnace

### 3.2 Human external Actions

The MORM model considers an implicit cognitive model where each human external action belongs to one or several cognitive functions according to the Cognitive Reliability and Error Analysis Method [5] (CREAM). These cognitive functions are: **observation**, **interpretation**, **planning**, and **execution**. In the furnace example, the external action “**Maintain**” (to ensure normal operation, essentially control of machine, ...) might be a planning and execution cognitive function. Besides, and according to the extended CREAM method, when executing an action it could be done correctly or with errors [5]. For example **maintaining**, the machine when being in the standby state, the operator might generate some errors; i.e. maintaining the induction furnace could be done with two planning errors :

- P1: Wrong device
- P2: Inadequate plan  
and five execution errors
- E1: Wrong device or Not enough lubricated
- E2: Time delay
- E3: Wrong device

- E4: Time delay
- E5: Action missed

Now that we described all main features of the MORM Model (Machine Protocol, changing machine states, cognitive functions, ...), we could present with more details the MORM Petri Net Model.

## 4 MORM Petri Net Model

Petri Nets (PN) is considered as a powerful formal specification tool used to describe a variety of systems including concurrent, distributed, asynchronous, parallel, and non-deterministic behaviors. Since the original model introduction, several progress have been made in order to modelize complex systems and provide the formalism with efficient and powerfull analysis methods. In the MORM project we use one of the more elaborated Petri Net model called CO-OPN. This model introduce several aspects that are especially suited to the purpose of the MORM project: Structuring and high level description of the data types. Several tools are available that allows simulation and basic analysis of the models.

### 4.1 MORM Machine Protocol Model

We translate the Machine Protocol into a Petri net model (Fig.4). The idea is that each machine state is a Petri net state and the changing machine states are the transitions. These transitions could be operator actions, machine-induced events or flow-induced events.

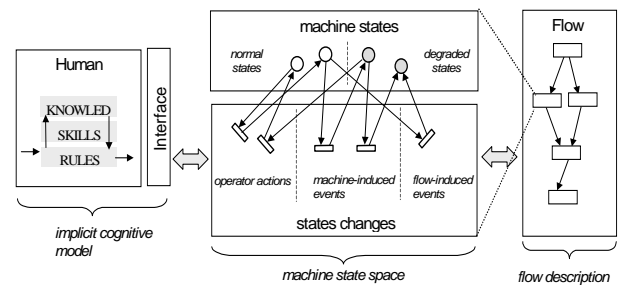


Figure 4 : Machine Protocol Petri Net

Considering this Machine Protocol, our induction furnace Petri net (Fig.5) describes the normal and degraded states and also the transitions between these states. To model our Man-Dynamic Process system we need a higher level and modular Petri Net formalism, let say Object-Oriented, supporting concurrency. That’s why we translate our model into CO-OPN. Thus in the following sections, we present the CO-OPN formalism and then the machine protocol model in CO-OPN. After that we deal with the machines’ inter-connection and how build the whole process.

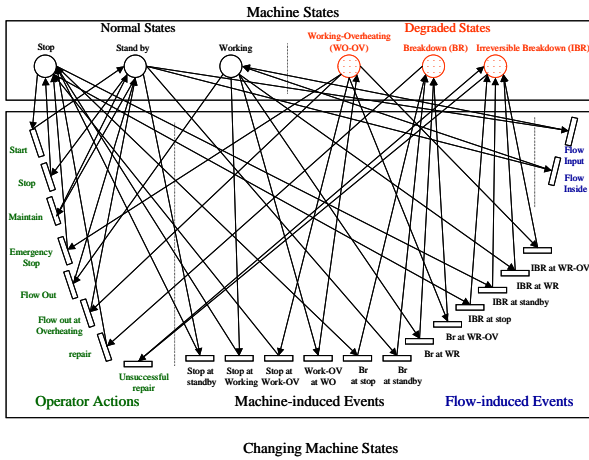


Figure 5 : Induction furnace Petri net

## 4.2 CO-OPN

CO-OPN is an object-oriented Modelling language, based on Algebraic Data Types (ADT), Petri nets, and IWIM (Ideal Worker Ideal Manager) coordination models [7]. One of the relevant principles of CO-OPN is that an object is an independent identity composed of internal states, and interact with its environment only by mean of its exposed services [10]. The inside part of an object is protected by the mechanism known as “encapsulation”, otherwise the only way to communicate with an object is to ask one of its services.

In CO-OPN formalism[10], an object is an encapsulated algebraic net in which the place compose the internal state and the transition model the concurrent events of the object. A place consists of a multi-set of algebraic values. CO-OPN/2 defines two transitions’ group: Methods or parametrized transitions corresponding to the object services provided to the outside and internal transitions that compose its internal behavior and are invisible to the exterior. In order to describe dynamic evolving systems, the objects are grouped into classes. A class describes all the common aspects of a set of objects.

Hence, CO-OPN concrete specifications are collections of ADT, class and context (i.e. coordination) *modules* [8]. Syntactically, each module has the same overall structure; it includes an *interface section* defining all elements accessible from the outside, and a *body section* including the local aspects private to the module. Moreover, class and context modules have convenient graphical representations which is largely used in the intuitive description of models, showing their underlying Petri net model. Low-level mechanisms and other features dealing specifically with object-orientation, such as sub-classing and sub-typing supported

by CO-OPN can be found in [8].

## 4.3 Building CO-OPN models for the Machine Protocol

Besides translating the Machine Protocol into CO-OPN consists on matching it with the corresponding CO-OPN specification modules.

The example of the induction furnace, as described previously, is considered as a box that “receives” energy, flow and human external actions and “produces” energy and flow. The changing furnace states are dynamically created and correspond in CO-OPN to a Class where transitions are fired under the influence of the external actions, the flow or the machine itself. Each class has a context defined as a set of methods and gates. Methods represent the incoming requests or actions and gates outgoing requests or actions.

The external actions and the flow are algebraic values represent in CO-OPN ADTs that describes one or more sorts.

For instance, the flow (input or output) is considered as values of an Algebraic Data Type, e.g the furnace has a flow input of billet and an output flow of hot billet since the induction furnace main function is to heat the billets. Characteristics of these billets are modelled quantitatively by means of ADTs taking into account its composition and its temperature. The abstract data types are considered qualitatively (by introduction of significant intervals) in the analysis process in order to deal only with the minimum of topologically related set of values.

## 4.4 Interconnection of Machines

Once the machine are defined in the CO-OPN formalism, we can link the different machines in order to build the process as shown in the figure 6.

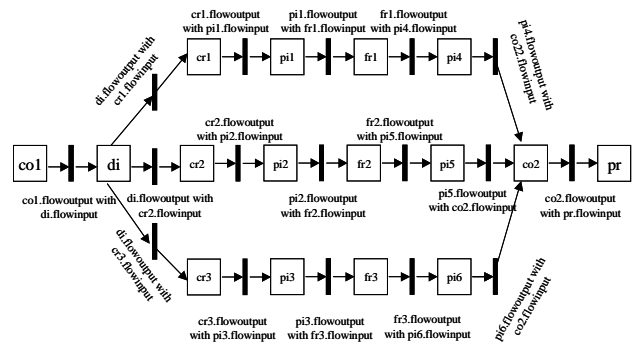


Figure 6 : Metal wire process “Machines interconnection”

In CO-OPN each machine is an instance of a Class. In

terconnecting the machines consists on linking the outgoing flows of a machine (output flow) with of the incoming flows of an other (input flow). This interconnection is ensured by a synchronization mechanism of CO-OPN. In the illustrative example, the billet is moved from a crawl (cr) into a furnace (fr) by a piston (pi). The billet represents the metal flow, and the interconnection between the crawl, the piston and the furnace is expressed by a synchronization of the flow movement since outgoing from the crawl into its delivery by the piston to the furnace. This interconnection (Fig.6) is summarized by two synchronization events:

1. cr.flowoutput **with** pi.flowinput,
2. pi.flowoutput **with** fu.flowinput.

The complexity of the machines interconnection depends on the number of the flows and also on the complexity of the flow (the number of relevant properties of the flow in the process : temperature, chemical composition, length, ...).

## 5 Analysis and expected results

Modelling the machines with a high level Petri Net was basically motivated by the simulation and analysis capability of such model. The future steps in our work will be first to simulate the whole process by building the reachability tree of the whole system and computing the probabilities to attempt a specific state. this will be done by adapting our current code generator integrated in the CoopnTools development environment [12]. In particular dangerous states will be mainly considered. The final step, will be to develop an analysis algorithm, built over the simulation tool, in order to extract manipulate additional risk and danger data based on timing aspects. Temporal extensions of CO-OPN [11] will be considered in order to manage such informations.

These main steps would be supported by corresponding softwares.

## 6 Conclusion

Risk analysis is currently based on manual construction of the causal relations of events leading to accident. In the MORM approach we propose to consider predictive methods were only limited accidental knowledge of the components are known. In this paper we have explored a techniques using modularity principles and probabilistic descriptions based on Petri Nets that can lead to dynamic prediction of risks induced by the complexity of the links between components.

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