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II. Machines Collaboration on a Shop Floor

Distributed Arrival Time Control for Real-Time Scheduling

Universidade do Minho

Curriculum Development
of Master's Degree Program in
Industrial Engineering for Thailand Sustainable Smart Industry

Real-Time Scheduling

Real-Time Scheduling: Determines the order of real time task executions

Types of Real-Time Scheduling: Dynamic vs. Static

- **Dynamic schedule** computed at run-time based on tasks really executing, priorities computed on the fly
- **Static schedule** done at compile time for all possible tasks, priorities are already known

Future Work of Real-Time Scheduling:

- **Enhancements in Multiprocessor and Distributed environments** resulting in better utilization of resources
- **Real time scheduling algorithms for Artificial Intelligent systems** that take decisions and prioritize execution of tasks based on heuristics
- **Context-Aware Scheduling:** the decision of which job to schedule next should be based on the deadline of the job as well as the context of resources being managed

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Distributed Control Systems

A **distributed control system (DCS)** refers to a control system usually of a manufacturing system, process or any kind of dynamic system, in which the controller elements are not central in location (like the brain) but are distributed throughout the system with each component sub-system

DCS is a computerized control system used to control the production line in the industry controlled by one or more controllers.

4 Basic Elements of Distributed Control System

1. Engineering PC or controller: This controller is the supervisory controller over all the distributed processing controllers.
2. Distributed controller or Local control unit: It receives the instructions from the engineering station like set point and other parameters and directly controls field devices.
3. Operating station or HMI: It is used to monitor entire plant parameters graphically and to log the data in plant database systems.
4. Communication media and protocol: Communication protocols selected depends on the number of devices to be connected to this network

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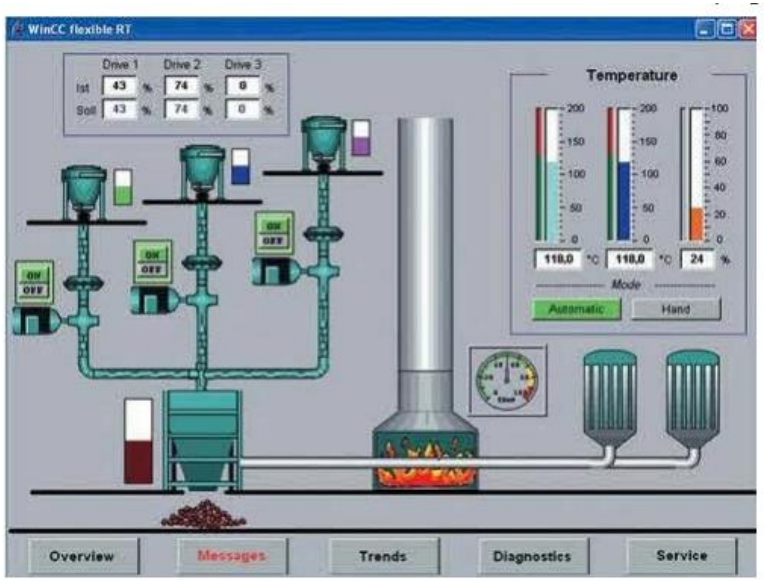
Distributed Control Systems

7 Important features of Distributed Control System

1. To handle complex processes:
2. System redundancy:
3. Lot of Predefined function blocks:
4. Powerful programming languages:
5. More sophisticated Human Machine Interface (HMI)
6. Scalable platform
7. System security



Sophisticated HM

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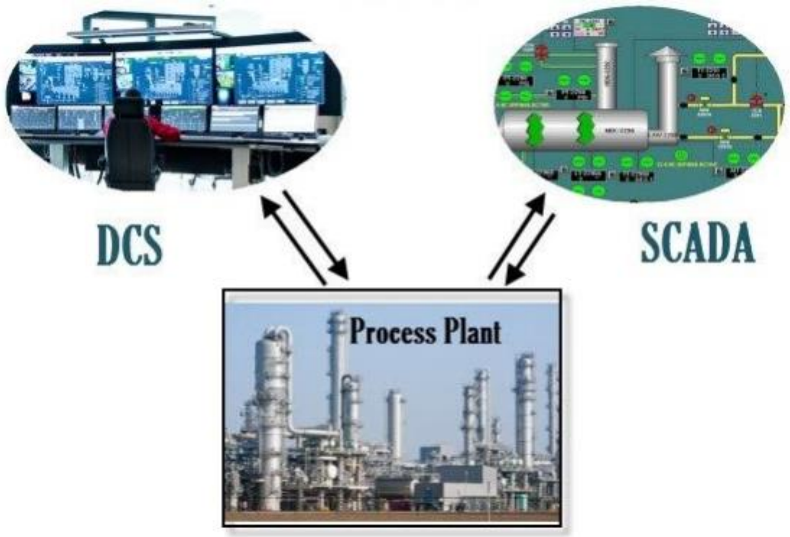
Distributed Control Systems

Difference between Distributed Control Systems (DCS) vs. Supervisory control and data acquisition (SCADA)



- DCS is process oriented, whereas SCADA is data-gathering oriented.
- In DCS, data acquisition and control modules are usually located within a more confined area and the communication between various distributed control units carried via a local area network. SCADA generally covers larger geographical areas that use different communication systems which are generally less reliable than a local area network.
- DCS employs a closed loop control at process control station and at remote terminal units. But in case of SCADA there is no such closed loop control.
- DCS does not keep a database of process parameter values as it always in connection with its data source, whereas SCADA maintains a database to log the parameter values which can be further retrieved for operator display and this makes the SCADA to present the last recorded values if the base station unable to get the new values from a remote location.

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Requirements of a Good Control System

The essential requirements of a good Control System can be listed as follows:

1) **Accuracy:** Accuracy must be very high as error arising should be corrected. Accuracy can be improved by the use of feedback element.

2) **Sensitivity:** A good control system senses quick changes in the output due to an environment, parametric changes, internal and external disturbances.

3) **Noise:** Noise is a unwanted signal and a good control system should be sensitive to these type of disturbances.

4) **Stability:** The stable systems has bounded input and bounded output. A good control system should response to the undesirable changes in the stability.

5) **Bandwidth:** To obtain a good frequency response, bandwidth of a system should be large.

6) **Speed:** A good control system should have high speed that is the output of the system should be fast as possible.

7) **Oscillation:** For a good control system oscillation in the output should be constant or at least has small oscillation.

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Controller Modes

In industry there are many control modes as follows:

- ON-OFF controller/two position controller
- Three-position controller
- Proportional Action Control (P)
- Integral/Reset Action Control (I)
- Derivative/Rate Action Control (D)
- P+I Control
- P+D Control
- P+I+D Control

P control
- P depends on the present error

I control
- I on the accumulation of past errors

D control
- D is a prediction of future errors, based on current rate of change

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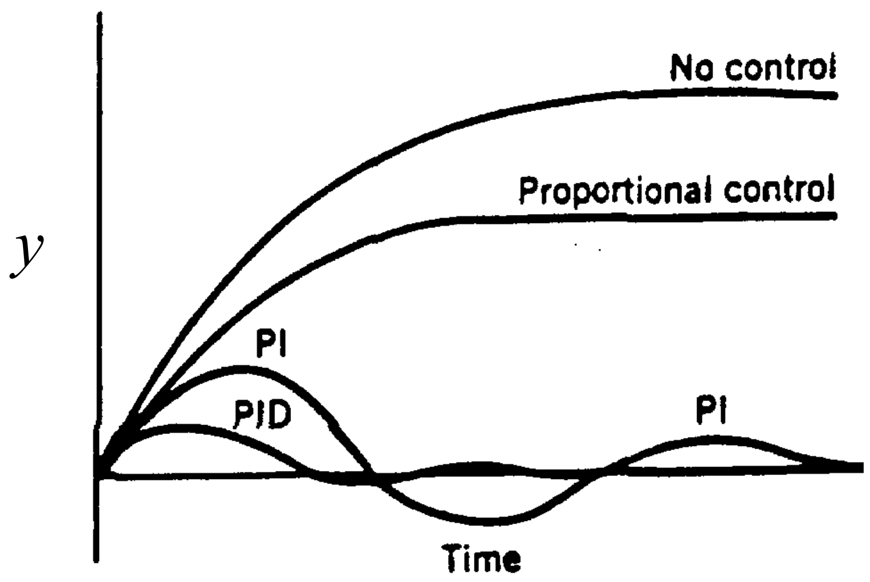
Controller Comparison

P
- Simplest controller to tune (K_c).
- Offset with sustained disturbance or setpoint change

PI
- More complicated to tune (K_c, τ_I) .
- Better performance than P
- No offset
- Most popular FB controller

PID
- Most complicated to tune (K_c, τ_I, τ_D) .
- Better performance than PI
- No offset
- Derivative action may be affected by noise

Typical Response of Feedback Control Systems



Consider response of a controlled system after a sustained disturbance occurs (e.g., step change in the disturbance variable

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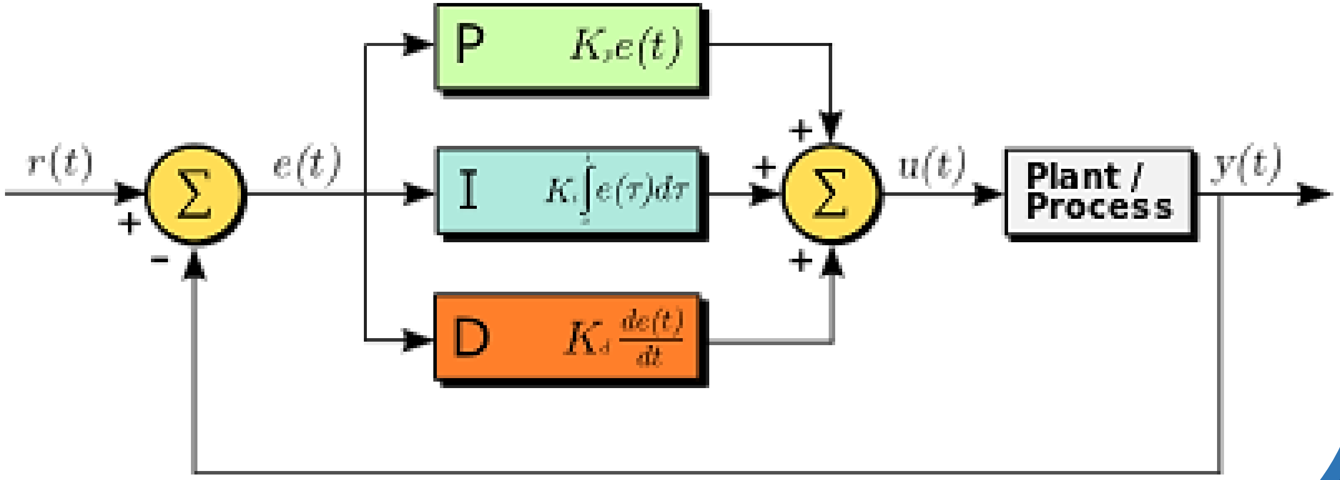
PID controller

- **A proportional–integral–derivative controller (PID controller)** is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control.
- **A PID controller** continuously calculates an error value as the difference between *a desired setpoint (SP)* and *a measured process variable (PV)* and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively)
- In practical terms it automatically applies accurate and responsive correction to a control function.



A block diagram of a PID controller in a feedback loop

- *r(t)* is the desired setpoint (SP)
- *y(t)* is the measured process value (PV).

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PID controller

P:Proportional action gives an output signal proportional to the size of the error. Increasing the proportional feedback gain reduces steady-state errors, but high gains almost always destabilize the system.

I:Integral action gives a signal which magnitude depends on the time the error has been there. Integral control provides robust reduction in steady-state errors, but often makes the system less stable.

D:Derivative action gives a signal proportional to the change in the Error. It gives sort of “anticipatory” control .Derivative control usually increases damping and improves stability, but has almost no effect on the steady state error

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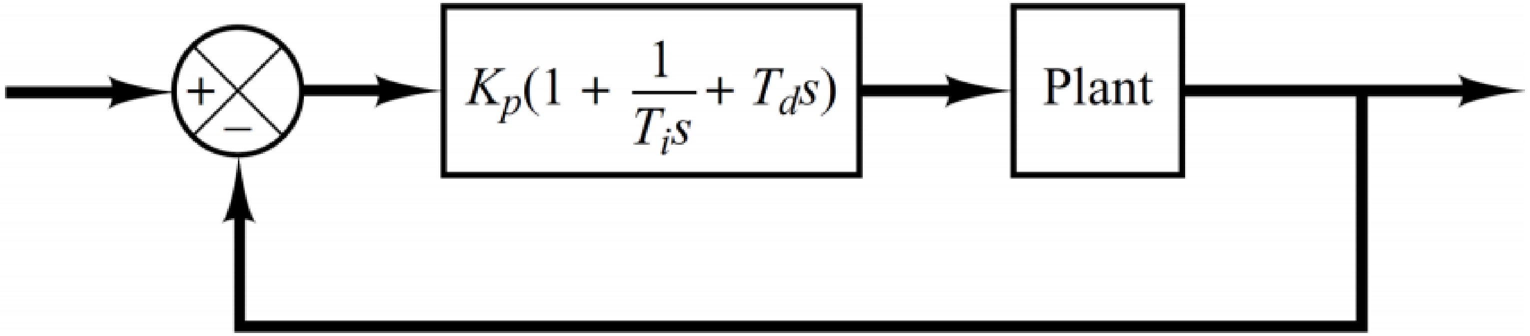
PID TUNING RULES

- The process of selecting the controller parameters (Kp, Ti and Td) to meet given performance specifications is known as controller tuning.



The tuning parameters essentially determine:

- How much correction should be made? The magnitude of correction (change in control output) is determined by the proportional mode of the controller.
- How long the correction should be applied? The duration of the adjustment to the controller output is determined by the integral mode of the controller.
- How fast should the correction be applied? The speed at which the correction is made is determined by the derivative mode of the controller.

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Distributed Arrival Time Control for Real-Time Scheduling

Integrated process control and condition-based maintenance scheduler for distributed manufacturing control systems (Koomsap et al., 2005)

Condition-based maintenance scheduling within the autonomous controllers in a distributed system

- An effective predictive maintenance program will also enhance manufacturing processes and result in a reduction of downtime, inventory and maintenance cost, while increasing process reliability.
- Conventional maintenance services are scheduled based on the availability of maintenance resources.

↓

The downtime might not be optimized if the machines are still in good condition, and the long downtime tends to decrease competitiveness

↓

Technology of sensory devices allows manufacturers to monitor their machines and to schedule the maintenance service based on the current machines' condition; consequently, the downtime can be improved.

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Condition-based maintenance scheduling has 3 major parts

1. Condition monitoring:
    - Identification of the possible faults.
    - Identification and measurement of the indicator variables of the faults.
    - Mapping the measured indicator variables to the machine/component condition.

2. Lifetime estimation: the remaining lifetime of the machine, the probability distribution of machine breakdown

3. Maintenance scheduling: Distributed arrival time control (DATC) is a feedback control-based scheduling approach that attempts to minimize the average of the square of the due-date deviation for JIT systems

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Distributed Arrival Time Control for Real-Time Scheduling

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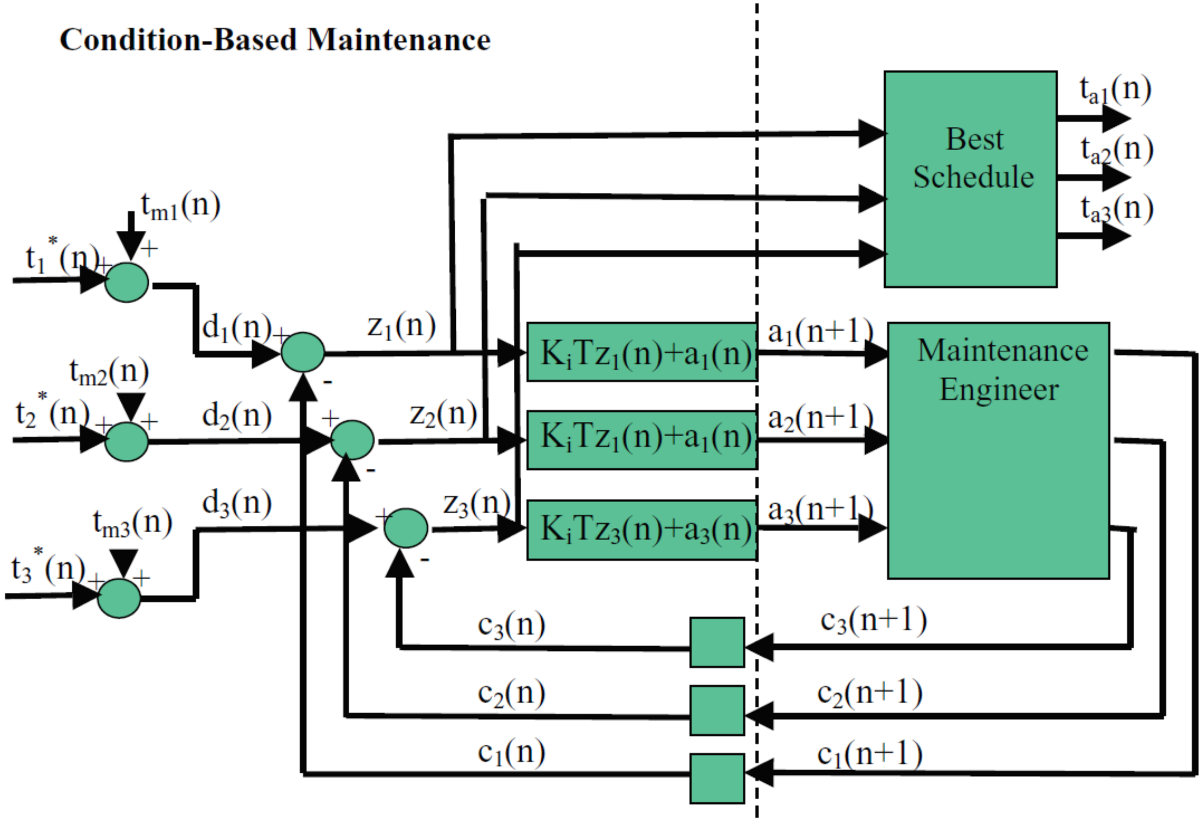
Based on distributed arrival time control (DATC):

- On-site controllers anticipate the remaining useful lifetimes of those machines, create the due-dates and make requests for service to a maintenance crew in terms of arrival time.
- Assuming the maintenance service time is known, the due-date is defined as the ideal completion time when maintenance service is executed at the time requested.
- The maintenance crew calculates the completion times and ends them to the appropriate machines.
- The sequence of services that gives the best global performance is selected.

Distributed arrival time control for maintenance scheduling



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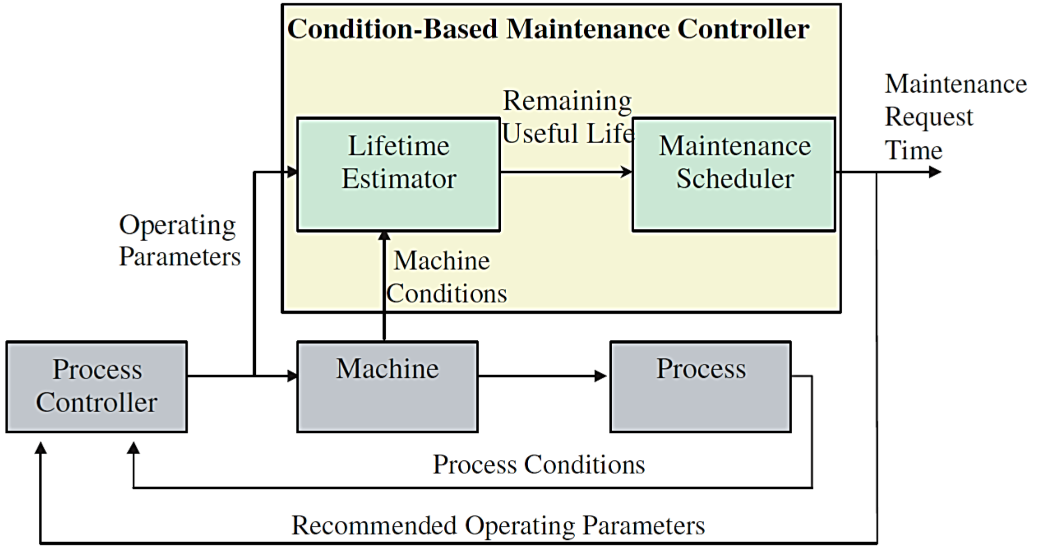
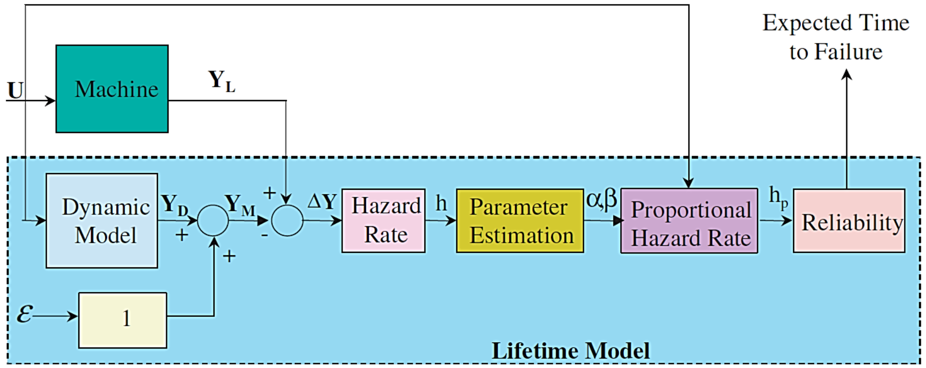


- **Within a distributed control environment,** each machine has its own monitoring sensors and intelligence that detect and isolate faults.
- **A distributed condition-based maintenance controller** is designed to detect faults, to anticipate the machine's condition, to recommend appropriate operating parameters to a process controller and to request maintenance service.
- **The lifetime estimator** is designed to predict the expected time to failure of a machine based on its current conditions.



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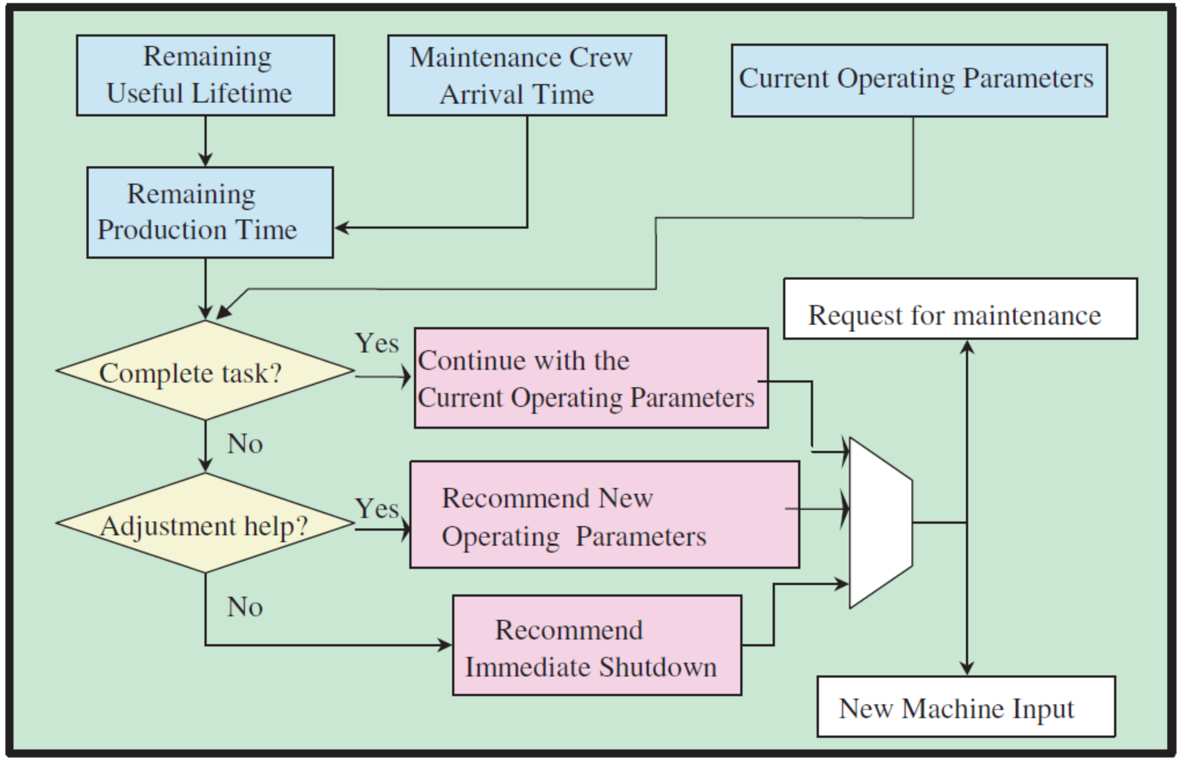
Schematic of a decision-making process in maintenance scheduling



- The maintenance-scheduling model recommends the operating parameters based on current condition of the machine.
- After it determines the remaining production time, which is the minimum value of the remaining useful lifetime and maintenance crew visiting time, it then decides whether the input should be changed or not.

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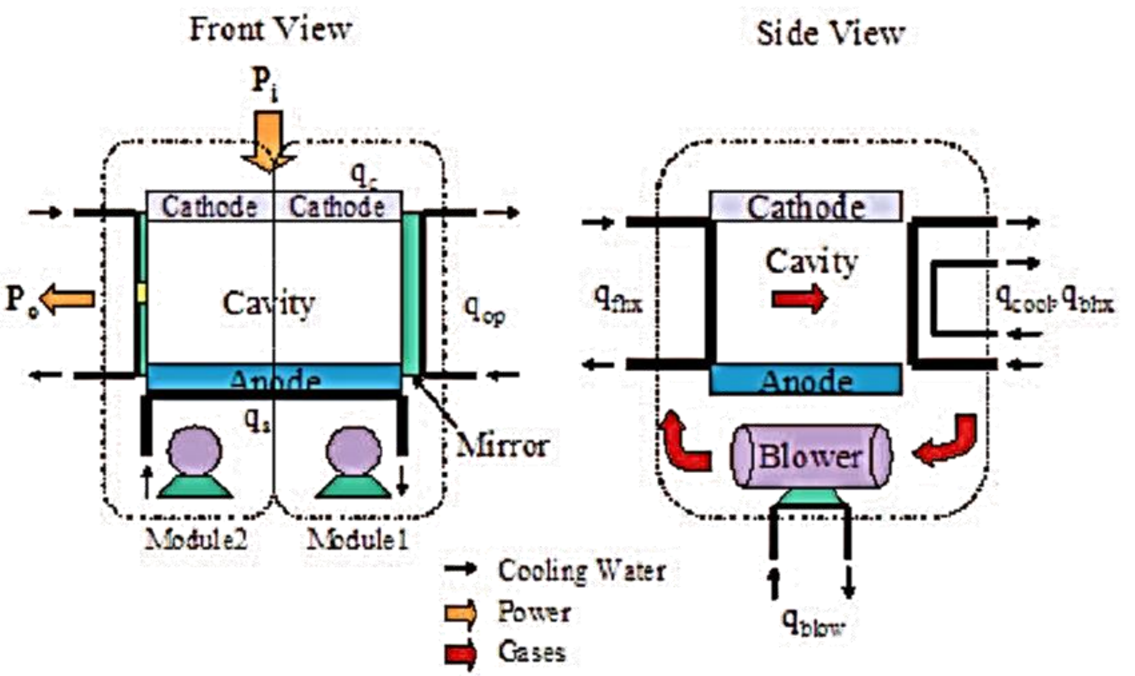
Case study: Coolant flow diagram of a 14-kW CO2 laser



Condition monitoring

- Identification of fault prone components: the errors that occur at the anode, cathodes, blower, and optic mirrors are monitored to estimate the remaining lifetime of the laser.
- Identification of indicator variables: the temperature at the back heat exchangers should be sensitive to the condition of the discharge electrodes.
- Mapping indicator variables to faults: the relationship between the power setting and the components, i.e. the anode, cathodes, blowers, and the optic mirrors.

Lifetime estimator

The remaining useful lifetime is a function of both the machine input (operating parameters) and the confidence level settings for the system.

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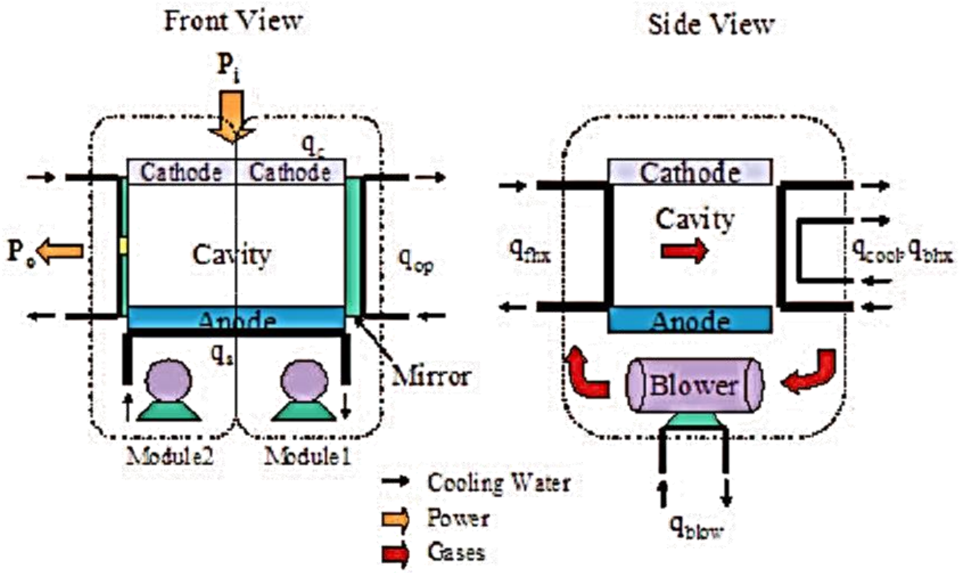
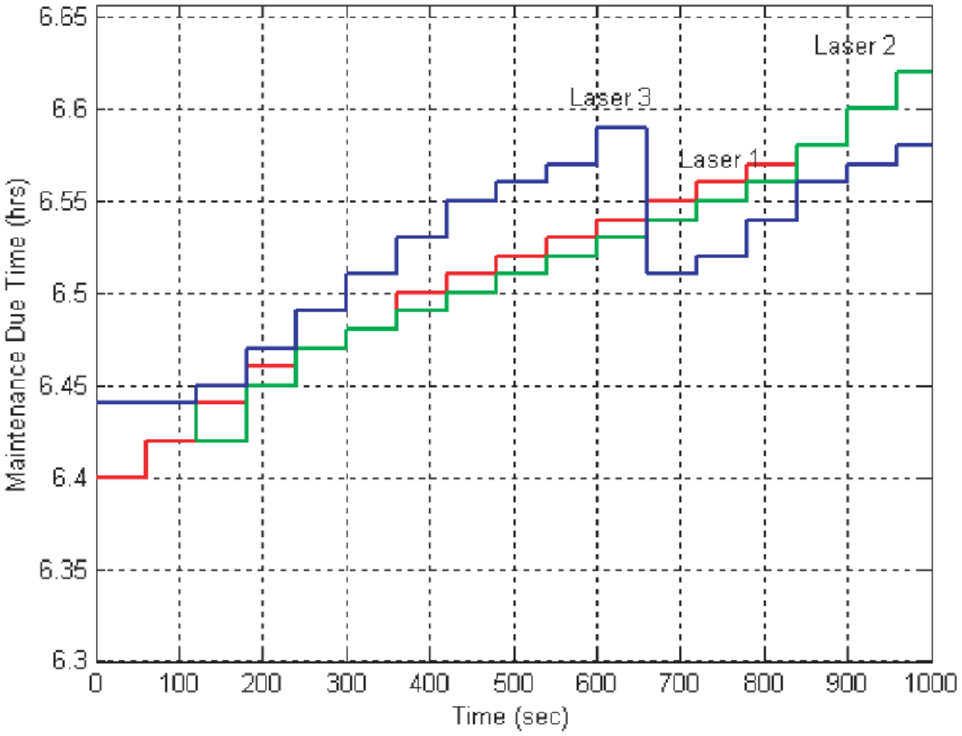


Prediction of Maintenance due date using DATC



The contributions of this development are prolonging the machine's lifetime and sustaining productivity by adjusting operating parameters and providing a ready-to-run condition-based maintenance controller that requires the dynamic model of the machine.

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