Systematic approach for the design of sustainable supply chains under quality uncertainty

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1. Introduction

During the last decade, industrial globalization has been continuously changing the business behavior, thus making it difficult to remain competitive in the global market for current processes/industries. Additionally, the increasing government pressure on designing green processes has led to the need for developing more sophisticated strategies to design and manage industrial processes. The above together with the recent improvements in environmental analysis techniques has stimulated the emergence of sustainability strategies in process systems engineering (PSE) literature. Nevertheless, such processes very often show variable conditions and present an uncertain behavior. The approaches presented for solving multi-objective problems under uncertainty have neglected the potential effects of different quality streams on the overall system. Here, it is presented an alternative approach, based on a State Task Network formulation, capable of optimizing under uncertain conditions, considering multiple selection criteria and accounting for the material quality effect. The resulting set of Pareto solutions are then assessed using the Elimination and Choice Expressing Reality-IV method, which identify the ones showing better overall performance considering the uncertain parameters space.

Sustainable processes have recently awakened an increasing interest in the process systems engineering literature. In industry, this kind of problems inevitably required a multi-objective analysis to evaluate the environmental impact in addition to the economic performance. Bio-based processes have the potential to enhance the sustainability level of the energy sector. Nevertheless, such processes very often show variable conditions and present an uncertain behavior. The approaches presented for solving multi-objective problems under uncertainty have neglected the potential effects of different quality streams on the overall system. Here, it is presented an alternative approach, based on a State Task Network formulation, capable of optimizing under uncertain conditions, considering multiple selection criteria and accounting for the material quality effect. The resulting set of Pareto solutions are then assessed using the Elimination and Choice Expressing Reality-IV method, which identify the ones showing better overall performance considering the uncertain parameters space.

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## Nomenclature

### Abbreviations
- **MO**: Multi-objective
- **SC**: Supply chain
- **MOO**: Multi-objective optimization
- **MILP**: Mixed integer linear programming
- **PSE**: Process systems engineering
- **SAA**: Sample average approximation
- **STN**: State task network
- **LCA**: Life cycle assessment
- **LCI**: Life cycle Inventory
- **G-ICE**: Gasifier Internal Combustion Engine
- **LV**: Low voltage
- **MV**: Medium voltage
- **LHV**: Lower heating value
- **MC**: Moisture content
- **OGM**: Operation and maintenance
- **VI**: Value of information
- **MFP**: Micronized food products
- **ANN**: Articialneuralnetwork

### Indices
- **s**: Material state
- **j**: Technology (treatment/pre-treatment equipment’s)
- **i**: Task
- **f**: Origin sites
- **F**: Destination sites
- **t**: Time period
- **c**: Scenarios
- **k**: Interval for piecewise approximation (economies of scale)
- **e**: Supplier site
- **m**: Market site
- **a**: Midpoint environmental category
- **g**: Endpoint damage category

### Sets
- **T**: Task that produce material s
- **Tc**: Task that consume material s
- **C**: Set of scenarios
- **Em**: Suppliers e that provide raw materials
- **Ep**: Suppliers e that provide production services
- **Epr**: Suppliers e that provide transportation services
- **FP**: Materials s that are final products
- **I**: Task i with variable input
- **Ij**: Tasks i that can be performed in technology j
- **If**: Technology that is available at supplier e
- **Ifj**: Technology that can be installed at location f
- **Ij**: Technology that can perform task i
- **JStar**: Technologies to perform storage activities
- **Mkt**: Market locations
- **Ntr**: Not transport tasks
- **RM**: Materials s that are raw materials
- **Sup**: Supplier locations
- **Tr**: Distribution tasks
- **x**: Optimal set of solutions for scenario c
- **y**: Space of uncertain parameters
- **KO1**: Ascending pre-ordered set of solutions
- **KO2**: Descending pre-ordered set of solutions

### Parameters
- **A**: Maximum availability of raw material s in period t in location f and for scenario c
- **Demc**: Demand of product s at market f in period t
- **Dc**: Distance from location f to location t
- **FCFc**: Fixed cost per unit of technology j capacity at location f in period t
- **FEdc**: Increment of capacity equal to the upper limit in interval k for technology j in facility f
- **InvestW**: Investment required for medium voltage
- **NORM_g**: Normalizing factor of damage category g
- **Pricec**: Price of product s at market f in period t
- **Pricec**: Investment required for an increment of capacity equal to the upper limit in interval k for technology j in facility f
- **FAsset**: Investment cost of technology j and for scenario c
- **FCF**: Fixed cost per unit of technology j capacity that is allowed at location j
- **FEr**: Minimum utilization rate of technology j capacity that is allowed at location j
- **FV**: Environmental category impact CF for the transporta-
- **CB**: Uncertain parameters vale
- **q**: Indifference threshold
- **p**: Preference thresholds
- **v**: Veto thresholds
- **Prob**: Probability of occurrence of scenario c

### Variables
- **Damc**: Normalized endpoint damage g for location f in period t and scenario c
- **Dame**: Normalized endpoint damage g along the whole SC for scenario c
- **EPurches**: Economic value of sales executed in period t during scenario c
- **ESaleses**: Economic value of sales executed in period t and scenario c
- **FAssetc**: Investment on fixed assets in period t and scenario c
- **FCostc**: Fixed cost in facility f for period t and scenario c
- **Fj**: Total capacity technology j during period t at location f and scenario c
- **FE**: Capacity increment of technology j at location f during period t and scenario c
- **HVe**: Lower heating value for material s during scenario c

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