SIZING INTERMEDIATE STORAGES
IN BATCH PROCESSING SYSTEMS
UNDER STOCHASTIC OPERATION
CONDITIONS

Theses of PhD Dissertation

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2003
Intermediate storages are often used in production systems. Processing units usually do not produce and use material to be processed at same rate so that in order to balance the operation differences of systems the material, in the case of need, is stored in intermediate storages. Similar problems arise when organising the operation of telecommunication systems using buffers. The purpose in the design of such systems is, in general, to determine the appropriate size of the storage in order to avoid the overflow, and/or to determine the initial amount of material to be processed required avoiding underflow, i.e. emptying the storage. A further problem may be to determine the capacity of the pipeline networks capable of transferring the material into or out of the intermediate storages without congestion.

The problem of the capacity of intermediate storages necessary to operate the processing systems without operation failures under deterministic and stochastic operation conditions has been studying by means of different models. When a processing system is operated under stochastic conditions, mostly the distributions of the stationary states are studied, or estimations based on the expectations of the amount of material in the intermediate storages are given. The stationary states and expectations, however, usually provide insufficient information for designing the operation of systems with high reliability. The reliability of the design and normal operation of the processing systems can be increased to great extent when considering also their stochastic dynamic states in determining the capacities of intermediate storages and pipeline networks, as well as the initial amounts of material required for normal operation.

The purpose of the dissertation was to develop methods for computer aided sizing of intermediate storages and determining the initial amounts of material with the aid of deriving and analysing their mathematical models using analytical and numerical methods. The main purpose of my work was to solve the sizing and initial amount problem in batch/batch and batch/continuous processing systems at a given reliability level in such applications when the overflow and underflow cause significant operation failures. Also, my purpose was to determine the capacities of pipeline networks required transferring the randomly sent batches of material without operation failures.
NEW SCIENTIFIC RESULTS

The main scientific results of the dissertation are summarized in the following theses.

Thesis 1

A method has been elaborated for sizing intermediate storages and determining the initial amounts of material in batch/continuous processing systems for infinite operation interval when the input process is described by one dimensional homogeneous Poisson process and the withdrawal rate of the material is constant.

- A Volterra-type integral equation has been set up for the function describing the reliability of no overflow, and a numerical method has been constructed for solving this equation for the case when continuous random variables describe the amounts of material filled into the storage.
- An integral equation has been developed for the function describing reliability of no overflow of the storage for the case when the material is filled into the storage at constant rate. This equation has been transformed into a delay differential equation and its unique solution was determined.
- On the basis of the derived equation, an algorithm has been constructed for determining the appropriate size of the intermediate storage at a given reliability level.
- A Fredholm-type integral equation has been developed for the function describing the reliability of no underflow in the storage when the model of the amount of material filled into the storage is a continuous random variable. Analytical solution has been derived for the case when the random variable is exponentially distributed.
- It has been proved that the derived equation always has an exponential type solution, and a numerical method has been elaborated for determining the exponent.
- An integral equation has been developed for the function describing the reliability of no underflow of the storage when the batches of material filled into the storage are constant. This integral equation was transformed into a differential equation with advanced argument, and its unique solution was derived.
- On the basis of the derived equations, an algorithm was formulated for determining the initial amount of material required to operate the system without failures at a given reliability level.

[P4], [P5], [P6], [P9]
Thesis 2

A method has been elaborated for sizing intermediate storages and determining the initial amounts of material in batch/continuous processing systems on finite operation interval when the input is described by one dimensional homogeneous Poisson process and the withdrawal rate is constant.

- It has been proved that the sizing problem and the problem of determination of the initial amount of material may not be solved simultaneously on infinite time horizon, thus the problem has to be formulated on finite time horizon.
- Integral equations have been developed for the two-variable function describing the reliability of no overflow and underflow when the amounts of material filled into the storage are described by random variables or are constant.
- A numerical procedure, based on the Monte Carlo method, has been elaborated for determining the functions at given time points.
- Integral equations have been developed for the three-variable function describing the reliability of no overflow and underflow when the amounts of material filled into the storage are distributed according to some general probability distribution or are constant.
- Using the solutions of the derived equations, an algorithm was formulated for determining the appropriate size and the initial amount of material require to operate the system without failure at a given reliability level.

[P5], [P6]

Thesis 3

A method has been elaborated for sizing intermediate storages and determining the initial amounts of material in batch/batch processing systems on finite operation interval when random failures of the operational units may occur during the operation:

- In the case of general input and output rates, the distributions of the maximum and minimum values of the function describing the variation of the amount of material in the intermediate storage have been determined by means of Monte Carlo simulation.
- It has been proved that the process can be built up of finite number of sub-processes.
• An algorithm has been elaborated to build up methods capable of reducing the numerical uncertainties of finding maximum and minimum values of a function.
• An algorithm has been formulated for determining the storage size and the initial amount of material required to operate the system without failures at a given reliability level.
• The distributions of the minima and maxima have been determined analytically, and a method has been formulated for finding the optimal delay time in the case of constant input and output rates and one input and one output unit.

[P2], [P3], [P10]

Thesis 4

A method has been elaborated for sizing pipeline networks transferring batches of material in batch processing systems when both the input and output processes are described by one dimensional homogeneous Poisson processes.
• An analytical formula has been derived for the distribution of maximum number of units working simultaneously as a function of time for the case of constant time intervals of inputs and outputs.
• A differential equation has been developed for the distribution of maximum number of units working simultaneously as a function of time, and the distribution has been approximated by an exponential formula for the case of constant times of inputs and outputs.
• An algorithm has been formulated for determining the distribution of the maximum number of units working simultaneously by using Monte Carlo simulation, and an exponential formula has been derived for approximating the reliability.
• Comparing the distribution of the maximum number of units working simultaneously in the case of generally distributed input/output times with that in the case of constant input/output times led to the conclusion that, when the relative dispersion of the random input/output times are small, the reliabilities are close to each other.
• An algorithm has been formulated for solving the sizing problem of pipeline networks at a given reliability level by reducing the problem of generally distributed input/output times to that of constant input/output times.

[P1], [P7], [P8]
APPLICABILITY OF THE NEW SCIENTIFIC RESULTS

Results can be applied in designing intermediate storages and buffers in material, energy and information systems, as well as in solving sizing problems of pipeline networks of the transport processes when the operation conditions are stochastic. The mathematical background and the algorithms formulated for solving these problems may serve as a basis of the engineering design procedures.

The methods elaborated may play extremely important role in designing environmental systems when operation failures due to the insufficient sizes of storages and pipelines may cause serious environmental damages. Also, these methods can be used in designing the operation of large logistical systems at high reliability level.

LIST OF PUBLICATIONS

Publications related to the theses

Journal papers


[P2] É. Orbán-Mihálykó, G. B. Lakatos: Intermediate storage in batch processing systems under stochastic failures

[P3] É. Orbán Mihálykó, G. B. Lakatos: Optimal delay times in operating intermediate storage in batch processing systems under stochastic failure


[P5] É. Orbán-Mihálykó, B. G. Lakatos: A buffered flow system with Poisson input and constant output rates
submitted to Operations Research Letters

[P7] É. Orbán-Mihálykó, B. G. Lakatos: Sizing of pipeline capacity in processing systems under stochastic operation conditions submitted to Computers and Chemical Engineering

Conference papers


Further publications


4. Cs. Mihálykó, **É. Orbán-Mihálykó**: A double stochastic model of the mixing of solid particles


8. Cs. Mihálykó, **É. Orbán-Mihálykó**: A double stochastic model of the mixing of solid particles


10. Süle Z., **Orbán-Mihálykó É.**, Mihálykó Cs.: Using statistical quantities for identification of mixing processes

11. Németh A., **Orbán-Mihálykó É.**, Mihálykó Cs.: Stationary states in the double stochastic model of mixing process
Presentations in international conferences

1. Z. László, É. Orbán-Mihálykó: Mathematical background of pipeline-networks’ reliability

2. Z. László, É. Orbán-Mihálykó: Some results on the increasement of Poisson processes

3. Z. László, É. Orbán-Mihálykó: Approximation of the distribution of increasement of Poisson processes
   PAMM Jubilee Meeting, Párizs, Franciaország, 1992. (oral)

4. Z. László, É. Orbán-Mihálykó: The distribution of the maximum increasement of Poisson processes
   Deutsche Mathematiker Vereinigung Jahrestagung, Jena, Germany, 1996. (oral)

5. É. Orbán-Mihálykó, G. B. Lakatos: Intermediate storage in batch processing systems under stochastic failures

6. É. Orbán-Mihálykó, G. B. Lakatos: Optimal delay times in operating intermediate storage in batch processing systems under stochastic failure

7. Cs. Mihálykó, É. Orbán-Mihálykó, Zs. Ulbert: On solving a model with random parameter of batch grinding
   Deutsche Mathematiker Vereinigung Jahrestagung, Mainz, Germany, 1999. (oral)

8. Cs. Mihálykó, É. Orbán-Mihálykó, Zs. Ulbert: Approximate method for solving a stochastic model of batch grinding
   The third Israeli Conference for Conveying and Handling of Particulate Solids, Ein Gadi, Izrael, 2000. (poster)

    7th Int. Symposium on Agglomeration, Albi, France, 2001. (poster)

    HUN-Pra-PARTEC International Conference on Practical Aspects of Particle Technology, Budapest, Hungary, 2001. (poster)

12. É. Orbán-Mihálykó, B. G. Lakatos: Modelling operation of intermediate storage in batch/continuous processing systems under stochastic conditions
    4th IMACS Symposium on Mathematical Modelling, Wien, Austria, 2003. (oral)

13. É. Orbán-Mihálykó, Cs. Mihálykó, B. G. Lakatos: On the delay and advanced integral and differential equations of the sizing procedure of storage devices