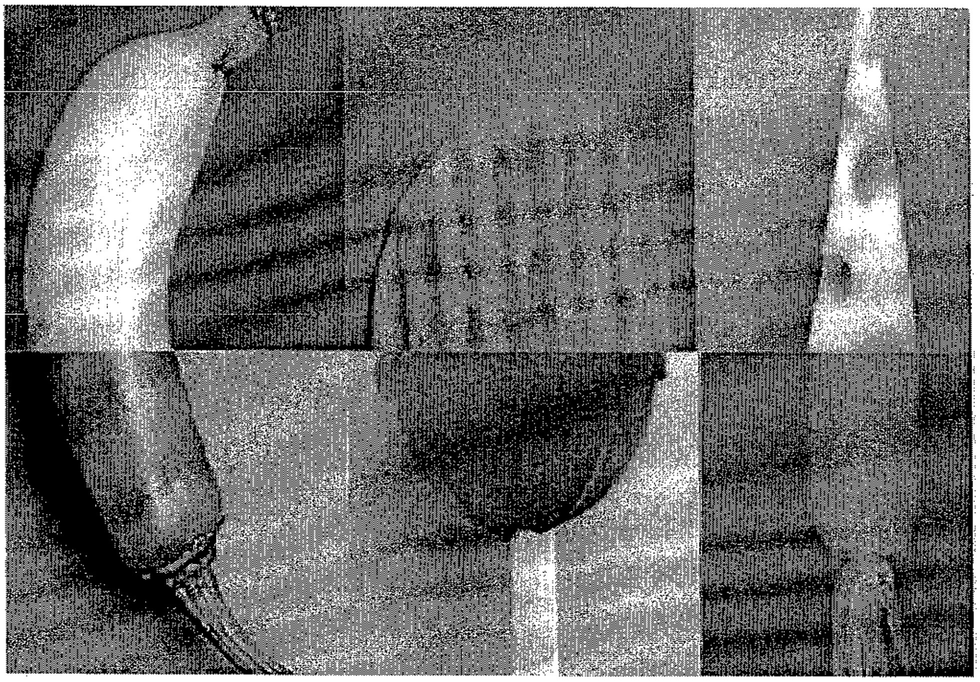
MASTER

Capacity determination of a batch process production system : a simulation study in flavour production

Quapp, J.M.

Award date:
2002



Capacity determination of a batch process production system

A simulation study in flavour production

Graduate report
J.M. Quapp
Naarden, 10th September 2002

Department of Operations Planning and Control
Eindhoven University of Technology

Capacity determination of a batch process production system

A simulation study in flavour production

Supervisor Quest: Richard White
Supervisors TU/e: Gudrun Kiesmüller
Marco Slikker

J.M. Quapp
Naarden, 10th September 2002

ABSTRACT

This report contains a description of a simulation study to investigate the capacity of a batch process production system. A simulation model is developed to calculate capacity on product type level expressed in number of batches produced per week. The simulation model captures bottleneck interaction effects caused by stochastic process times. Sensitivity to several parameters is analysed and applications for this model are discussed.

ACKNOWLEDGEMENTS

I would like to thank the people at Naarden Food Operations for letting me do my graduate project at Quest International. A lot of great people supported me during my time here. I will especially thank Richard White for helping me get the resources and information for this project and Tom Malik at ICI's Strategic Technology Group for supporting the actual modelling effort. Also, I should thank my academic supervisors, Gudrun Kiesmüller and Marco Slikker, their critical comments and suggestions during this project have been very helpful. Finally, I thank friends and family for their patience and support.

SUMMARY

Introduction

The original assignment was to improve the current capacity model for the FLE/P large scale liquid compounding factory since it is primarily focused on equipment and does not take into account labour resources.

Problem analysis

Up to now the capacity of the FLE/P large scale was calculated using a very simple model. The outcome was 8,18 batches per shift corresponding to 24,54 batches/day The planned production output is 12 batches/day at this moment and the average daily output during a week's measurement was 7,14 batches/day. Figure I shows a plot of the actual output for FLE and FLP product types against planned output, outcome of original capacity calculation and the outcome of the original capacity calculation with "worst case" settings.

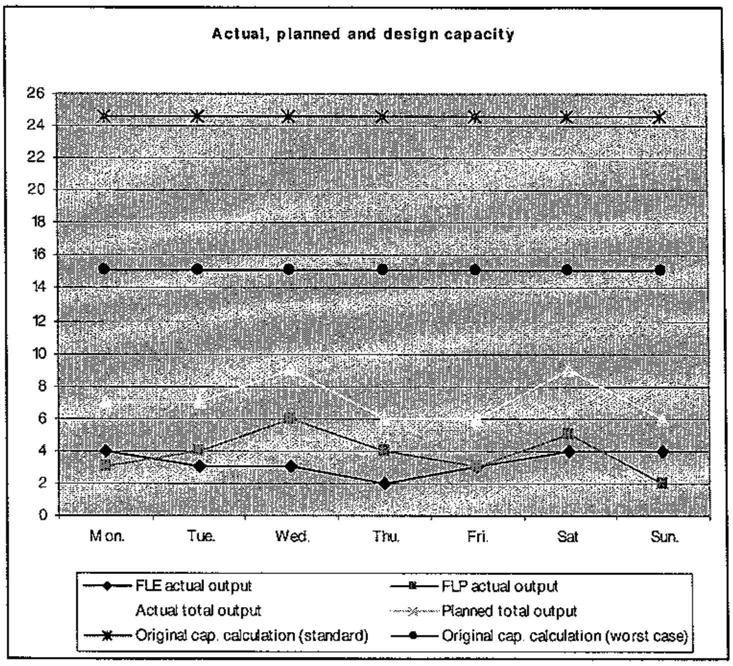


Figure I Actual vs. planned output and design capacity week 10 A0 to A4

The figure shows production targets are structurally not met, which led to the following problem definition:

The actual production output is smaller than planned production output and design capacity.

This problem then was decomposed into possible causes related to planning and causes related to execution. The difference can be caused by planning more orders than the factory can handle or by problems at execution level.

The production system and production control have been carefully analysed. Also, data has been collected and analysed to determine performance of planning methods used for FLE type products and what are causes for lost time at preparation tanks. The analysis showed that both on the planning and execution side there are issues causing the difference between planned and actual output.

With respect to planning the analysis showed that planning and scheduling of both product types is based on deterministic process times while the measurement showed process times are in fact stochastic. It is therefore not possible to determine a seamless production schedule. Also, in scheduling of FLP type products labour is not taken into account. Furthermore, analysis showed the workload model used to schedule FLE process orders does not accurately predict labour workloads.

On the execution level, measurements have shown that time is lost because of waiting for shared resources, issues regarding raw material and recipes and operator availability. Also, preparation times found in the measurement are larger than the standard batch times used for the original capacity calculation. Analysis of the production system showed waiting for shared resources is caused by stochastic process times that lead to interaction between bottlenecks. Resource utilizations are directly influenced by other bottlenecks, a phenomenon that does not occur in discrete manufacturing

Assignment
The analysis showed stochastic process times leading to interaction between bottlenecks are the main cause the original capacity calculation is unrealistic.
Due to complex effects, like interaction of bottlenecks, which are hard to capture in solvable analytical models the approach became to calculate capacity numerically by simulation. The assignment then becomes:

Determine the capacity of FLE/P large scale liquid compounding by simulation

Capacity is considered on product type level, e.g. FLP and FLE type, and expressed in batches/week. Simulation involves construction and analysis of a mathematical model. In this study a discrete-event model has been used.
Having defined the assignment for this graduate project, first the information needed is consolidated. Then a conceptual model is created that defines the system, its components and their relations. During data collection and definition of the conceptual model, validity is ensured by using different sources of information such as:

- Operators
- Engineers
- Plant design documents
- Own observations

Next, the model was developed in a computer program, which has been tested to verify functionality and eliminate any bugs The software chosen is called Extend v5 +BPR +Mfg. The computer model was validated by evaluating pilot runs. The outcome of these pilot runs was expected to fall between the actual output during the measurement and the capacity calculation with "worst case" process times. Then several experiments are done to analyse sensitivity of parameters and to increase understanding of system behaviour.

Description of discrete-event model and key assumptions
First the model's main characteristics are discussed. Then the most important assumptions are summarized. Finally, simulation results are shown.
The model considers the entire production system, preparation tanks, downstreaming equipment, CIP, pack tanks, packing lines and operator resources.
Process times in the model are stochastic or deterministic. Data captured during the measurement has been used to estimate parameters for a Gamma distribution. In other cases empirical tables have been constructed.
An empirical table was also constructed for technical delay time. For each batch a draw from this table is added to preparation and mix time.
Several other parameters are also needed for the model, such as the ratio of FLE and FLP type batches produced, fraction of juice based compounds, fraction of batches needing intermediate homogenization, fraction of batches needing rework, fraction of batches needing filtration and batch size distributions for both product types Some of these parameters could be estimated based on historical data, for the others a value was chosen based on operator experience.
Several assumptions have been made for the model. They are related to the entire system, operator behaviour, preparation, intermediate processes, downstreaming and transferring, cleaning, storage and quality control, and packing. Some key assumptions are:

- Recipes and raw materials are always available.
- Batches are processed first in first out.

- Operators are available for both product types.
- No difference between preparation tanks with respect to dosage capabilities and dosing speed.
- All batches are packed in the packing hall.
- Allocating equipment does not require any labour

The capacity calculated by the model is expressed in a 95% confidence interval. It is chosen to do 50 runs each time to satisfy the condition that the confidence interval may have a maximum length of 4 batches. The mean number of batches to be produced is estimated as $\overline{x} = 70{,}18$ and the corresponding standard deviation is 5,68 leading to a confidence interval of [68,57 ; 70,79].

Experiments
Several experiments have been conducted with the model to gain insights on system behaviour. The experiments were executed similar to sensitivity analyses:

- Removing technical delays
- Varying the level of operator resources
- Reduction of mean preparation and mix time
- Variation of the product type mix
- Variation of the fraction of juice based compounds within FLP type products
- Variation of the fraction of batches needing intermediate homogenization
- Addition of delays in pack tanks
- Variation of the fraction of FLP type batches needing rework.

Applications and conditions
The simulation model and its results have several possible applications. These applications have a long term or medium to short term horizon.
Long range capacity planning, called Sales and Operations Planning at Quest, can be supported by the model. Periodically, capacity can be evaluated using updated input data. The results of these periodic capacity reviews can be used as input for Sales and Operations Planning. Also, the simulation model can be used to support capacity adaptation decisions. The capacity effect of decisions can be estimated using the model.
On the medium to short term, the insights provided by the model through the experiments can help managers focus improvement efforts. The experiments show to which parameters capacity is sensitive. These parameters should receive the most attention from management.
Also on the medium to short term, the simulation model can also be used for operator training. The effect of certain behaviours can be shown using the model. For example, the model assumes equipment is cleaned the first moment possible. An experiment can show the effect if operators do not start CIP at the first moment possible.
There are conditions for the model to function properly in these applications. The input data should be kept up to date. The model itself must be updated if underlying assumptions no longer apply. The simulation model needs a front-end that allows easier data entry and analysis increasing accessibility to a wider range of people. When the model is used for operator training the animation needs to be improved to make the factory recognizable.

Conclusions
A simulation model is developed to calculate capacity at product type level, e.g. FLE and FLP type, expressed in batches/week. The results of the simulation model are different from the original capacity calculation. The simulation model computes a capacity of $\overline{x} = 70{,}18$ and the original capacity calculation of 172,78.
The simulation model is different from the original capacity calculation. Key differences are:

- Process times are stochastic.
- Entire system is considered.
- Labour is considered explicitly.

The experiments led to the following conclusions, ordered in descending effect on capacity:

- Reducing technical delays can improve capacity to about 78 batches/week.
- In the base case (4 operators) the operator resource level is an important bottleneck. Capacity becomes larger with a decaying rate when the resource level is increased. A coarse economical evaluation taking in account positive cashflows due to increased sales, negative cashflows due to extra operator costs and opportunity cost of working capital indicated it is economically justified to increase the operator resource level. After a more detailed analysis of the contribution margin per batch a final conclusion can be drawn.
- Reducing preparation and mix time by training, increasing dosage pump rates or improving agitation will increase capacity. However, capacity will not reach the level in the original capacity calculation.
- The ratio of FLE and FLP type batches in the product mix has a big effect on capacity. This has an implication for planning that the mix of process orders scheduled on a day influences daily output.
- Capacity decreases slightly if the fraction of juice based compounds increases, due to a higher utilization of the juice transfer line.
- The fraction of batches needing intermediate homogenization does not influence capacity.
- When a deterministic delay in the pack tanks is added capacity decreases at a growing rate. The effect is small at first (delays smaller than 3 hours) but increases rapidly when pack tanks become a bottleneck.
- The fraction of rework influences capacity negatively because rework places an extra demand on labour. However, the effect is slightly smaller than expected, because labour shifts from preparation of FLE type batches to rework.

Currently, the operator resource level and the juice transfer line are the most important bottlenecks However, when these bottlenecks are solved other resources will be come a bottleneck. Dependent on model parameters these can be the preparation tanks, packing lines, 6000 ltr. pack tanks or CIP ring 1.

Recommendations

The simulation model developed in this project should be used to support long range capacity planning. Model results should be used as input for Sales and Operations Planning, the model itself to support capacity adaptation decisions by evaluating capacity effects of possible decisions. However, input data and assumptions should be maintained to keep the model up to date.

The model should be used in making the trade-off between capacity and operator resource level.

Consider simulation in the design of other factories, when sizing the plant, if process times are stochastic and production processes need several resources.

INTRODUCTION

This is the final report of a graduate project for the Eindhoven University of Technology The graduate project is the final stage in the curriculum of Industrial Engineering and Management Science and is concerned with solving an existing problem in a company at an academic level. The assignment has been done under supervision of the Department of Operations Planning and Control (OPC). The graduate project consists of two phases, an analysis phase and a design phase. During the analysis phase a problem is analysed to determine what the causes are. The design phase is meant to develop a model to improve the situation.

The project has been done at Quest International. The original assignment was to improve the current capacity model for the FLE/P large scale production department because it is focused only on equipment and does not take in account labour resources. The first 3 months were spent on analysis of the production system, the next 4 months on the development of a simulation model for calculating the department's production capacity.

This report informs all involved what has been achieved. The results of both the analysis and the design are discussed and justified.

First the company is briefly described in chapter 1. In chapter 2 a brief analysis of products is made. In chapter 3 the processes and the factory layout are described to understand factory capabilities and constraints. Production control is investigated in chapter 4. Chapter 5 describes the problem analysis and definition of the assignment. Chapter 6 describes the development of the simulation model. Experiments are carried out with this model. The design, execution and analysis of these experiments is discussed in chapter 7. Several applications for the simulation model as well as conditions for effective use are explained in chapter 8. Finally, in chapter 9 conclusions are drawn and recommendations are made.

TABLE OF CONTENTS