Sustainable Development in Mechanical Engineering

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Case Studies in Applied Mechanics (2nd Edition)

Edited by

Sylvie Nadeau, Yvan Petit,
Stéphane Hallé, François Morency
and Louis Dufresne

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

PREFACE

The professional practice of engineers around the world is increasingly complex. They play a crucial role in the design and development of new products or infrastructure as well as in the creation of wealth. To perform through this reality, engineers must acquire multidisciplinary technical expertise, as well as personal skills.

Sustainable Development in Mechanical Engineering: Case Studies in Applied Mechanics is the product of many years of teaching experience and interdisciplinary collaboration in mechanical engineering. This book is an attempt to favour the assimilation of knowledge and abilities in all disciplines of mechanical engineering with a special perspective of considering the impact of engineering projects on several other aspects such as legal, social, economic, health, environmental and communication.

The intent of the book is to provide educational tools to professors and students in mechanical engineering. It is desirable for every professor to support its teaching with tools which help motivate students to master the competencies that are most often used in engineering. From the student point of view, it is important that examples used to develop their knowledge are representative of what actually exists in their future field of practice.

Sustainable Development in Mechanical Engineering: Case Studies in Applied Mechanics provides a broad overview of cases applying analysis, synthesis and evaluation aptitudes in a new and innovative way. Every case was developed from current engineering problems. This book gives the future engineer tools to quickly and efficiently integrate the knowledge of several disciplines and to become aware of their role in a larger business and societal context. We hope this book will provide an exciting way to develop state of the art engineering skills.

ACKNOWLEDGEMENTS

The Editors and Authors wish to express their gratitude for the assistance they have received from a number of different sources, including those mentioned in more detail below, in obtaining much of the material included in this monograph as well in putting everything together.

It is the result of more than a decade of collaboration between a good number of people which all deserve our recognition. More specifically, we thank Ms. Andréanne Bouchard for her illustrations of the different cases, Ms. Jennifer Sunde for the translation of the cases originally written in French, and Ms. Jocelyne Dumont for all the typing work. We also wish to acknowledge the collaboration to various degrees of Professors Philippe Bocher, Henri Champliaud, Jean-François Chatelain, Jean-Luc Fihey, Stanislaw Kajl, Frédéric Laville, Van Ngan Lê, Jacques Masounave, Anh Dung Ngô and Victor Songmene.

This work has also been made possible through the financial support over the years from different branches of the École de technologie supérieure: Décanat à la recherche et au transfert technologique, Décanat des études, Département de génie mécanique and Équipe de recherche en sécurité du travail. Our last word would be to thank the many students who worked, at one time or another, on these cases and helped improving them by their comments and observations.

CHAPTER ONE

CASE STUDY: GASKET TEST RIG

H. A. BOUZID, S. NADEAU, J.-P. KENNÉ

Summary

This case study will focus on designing a rig to test the leakage performance of gaskets. By presenting this as a case study, engineering students will be able to work in multidisciplinary projects. This case study will combine knowledge in human factors engineering, hydraulics and strength of materials in the course of designing a test rig for gaskets. Students will use knowledge from each of these fields to solve the problems presented in this study. Results obtained from these studies will assist professors in carrying out other projects or case studies.

Keywords: Human factors engineering, hydraulics, strength of materials, gaskets, bolted joints

1. Key Considerations and Objectives

A researcher in the field of tightness for bolted flange gasketed joint assemblies would like to equip his laboratory with a test rig with which to measure leakage from different gasket types. He wishes to reproduce the industrial conditions of pressure vessel bolted joints.

A model for fluid leakage already exists. This model is based on the porous structure of the gasket, its geometry, the type of gas used in the pressure tank and certain thermodynamic parameters. The researcher would like to accurately measure the amount of leak from the gasket. Thus, to improve the model's predictions, he proposes to measure leaks as a function of the compressive load, gasket thickness, type of gas used and operating pressure.

To be able to continue with his other projects, he has decided to entrust the design of the gasket test rig to junior engineers.

In this case study, we will examine problems concerning test rig design. More specifically, our objectives will be to:

- Conduct a conceptual design study of a gasket test rig and establish its dimensions;
- Analyze test rig safety and safety measures to prevent risks during operation (inhalation, explosion, etc.);
- Design the required hydraulic and pneumatic control systems.

2. Facts

2.1 Specifications

The following table lists the conditions of usage that must be reproduced.

Table 1-1: Conditions of usage

Condition	Value
Maximum operating pressure	1000 psig
Operating temperature	Ambient
Test gas	Helium, Nitrogen
Level of leakage rate to be measured	1 to 0.0001 cm^3/s
Testing time	48 hours
Gasketed joint geometry	Max. external diameter 6.19 in Min. internal diameter 4.50 in Thickness varying from 1/16 to 1/8 in

2.2 Operating Mode

The objective of this test rig is to measure leaks from various gaskets according to several parameters, namely the bolt tightening load, thickness of gasket and gas pressure. The test rig is a bolted joint composed of two pieces of pipe sealed at each extremity. Each pipe is welded to a 4-inch diameter flange and the entire piece is assembled with bolts. The gasket rests between the two flanges (see Figure 1-1).

The operator first installs the gasket between the two flanges and then tightens the bolts to the required load. The bolts are tightened using a hydraulic tightening device placed on each bolt. The hydraulic tightening devices are actuated by a hydraulic system to ensure even tightening pressure.

The operator then introduces pressurized fluid into the assembly. To do so, the operator sets the fluid pressure using a proportional valve. The regulator limits the maximum pressure while the dial gage provides a visual reading. Once the correct pressure is obtained, the operator closes the diaphragm valve using a pneumatic actuator (see Figure 1-1). Leakage may then be measured by:

- a flow meter for major leaks; or
- a drop or rise in pressure for minor leaks.

All data is collected and sent to a computer through a data acquisition system. The various measuring instruments are:

- a pressure transducer to measure inlet gas pressure;
- a thermocouple to measure temperature in the pressure drop system;
- strain gages to measure bolt elongation;
- a linear velocity displacement transducer to measure gasket deflection.

Once the test is completed, the operator shuts the system down, opens the purge valve and empties the bolted joint assembly in preparation for the next test with a new gasket.

2.3 Safety Measures

If at low pressure major leakage is observed, the operator must increase the bolt load and continue with the leakage measurement procedure. The system is equipped with a safety relief valve to prevent over pressurizing the joint assembly.

3. Questions

Faced with a tight budget, the researcher must carefully plan his design. Should priority be given to flange size selection: class 600 or 900? Would you suggest bolts or studs to be purchased? Which hydraulic components should be used? Which control system should be selected to adjust the proportional valve? Have all safety measures been implemented to prevent incidents and accidents with or without material losses and injuries?

The main objective of this test is to measure leakage from the gasket being tested. All other rig components must be leak proof. Which design strategies must the researcher prioritize to ensure this? How will the researcher measure leaks from the gasketed joint?

The test rig will be used for teaching purposes. Therefore, the researcher would like the work station to be ergonomic and safe. He fears it may be used improperly. He must take into account safety margin requirements when designing the rig and must comply with machine safety standards and the applicable pressure vessel code.

The solution that will be chosen will undergo further study in the following aspects:

3.1 Strength of Materials

Refer to the conditions of usage provided in sections I Problem and II Facts to review the problem specifications.

Suppose a 4-inch diameter flange joint.

- Verify the mechanical integrity of the test rig structural components, namely the flange (material, thickness, class or grade), bolts (material, quantity and length), tank (material, thickness, dimensions).
- Specify the maximum bolt load capacity knowing that cyclic loading will be conducted on the gasket, without exceeding a maximum gasket stress of 23,000 psi.

3.2 Hydraulic and Pneumatic Systems

Refer to the conditions of usage described in sections I Problem and II Facts to review the problem specifications.

Select each of the hydraulic and pneumatic components for the test rig (tubes, valves, connections, and hydraulic and pneumatic devices).

You are asked to design a hydraulic system and select hydraulic tightening devices to tighten the bolts (pump, tank, channels, oil, etc.).

Also, the bench test rig manufacturing costs are to be kept to a minimum. You are asked to propose a system to control the proportional valve (setting, feedback and actuator). The hydraulic system maximum pressure should be established in accordance to the operating conditions of the test rig.

3.3 Ergonomics and Occupational Safety

Verify that the test rig complies with the act respecting occupational health and safety and the regulation on occupational health and safety.

Consult machine safety standards and propose safety measures to prevent risks during operation.

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References

Department of Defense, Design Criteria Standard Human Engineering, MIL-STD-1472F, États-Unis. [Internet]. Available from: www.hf.faa.gov/docs/milstd14.pdf.

Labonville, R. *Concepts des circuits hydrauliques : une approche énergétique*. Éditions de l'École Polytechnique de Montréal, 1991.

Lupin, H. et Marsot, J. *Sécurité des machines et des équipements de travail. Moyens de protection contre les risques mécaniques*. Édition INRS ED 807, France, 2000.

Merritt, H.E. *Hydraulic Control Systems*. John Willey & Sons, New York, 1993.

Rabardel, P., Carlin, N., Chesnais, M., Lang, N., Le Joliff, G. et Pascal, M. *Ergonomie concepts et méthodes*. Éditions Octares, France, 1998.

Regulation on occupational health and safety. *Gazette officielle du Québec. Décret 885-2001*.

Sullivan, J.A. *Fluid Power System: Theory and Applications*. 3rd edition, Englewood Cliffs, New Jersey, 1989.
The *Act Respecting Occupational Health and Safety*, R.S.Q., Chapter S-2.1.

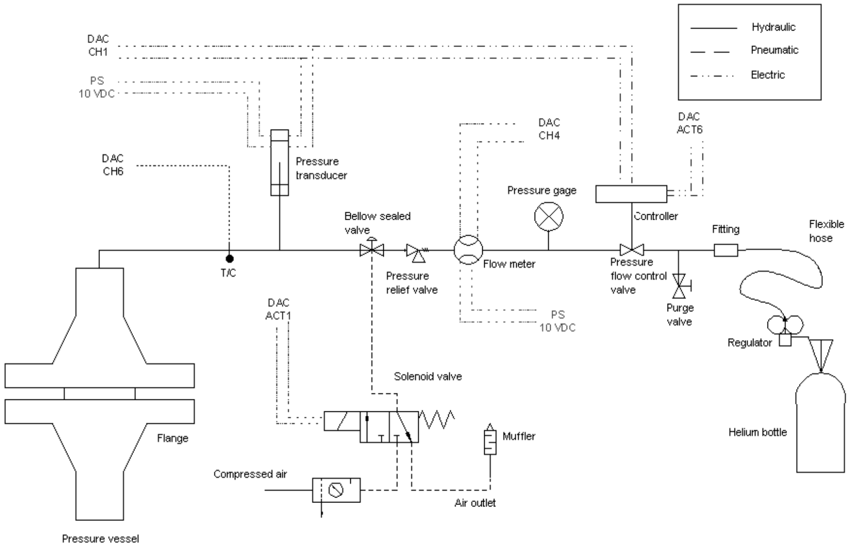

Figure 1-1: Pressurization and leakage detection system

CHAPTER TWO

CASE STUDY: DESIGNING A LOG SPLITTER

H. A. BOUZID, J.-P. KENNÉ, S. NADEAU, T. GOWINGS

Summary

This case study will focus on designing equipment used to prepare firewood. The case study format is used to enable engineering students to work on multidisciplinary projects. The purpose of this case is to combine knowledge in human factors engineering, fluid power systems and strength of materials to design a log splitter. Students will use material learned from each of these fields to solve the problems presented in this case study. Results obtained from this study will enable professors to carry out further projects or case studies.

Keywords: Human factors engineering, fluid power systems, strength of materials, log splitter

1. Key Considerations and Objectives

Any fireplace, woodstove or wood furnace owner must eventually stock up on firewood, and this implies chopping wood to the right size for use. A splitting maul and chainsaw are obvious tools at one's disposal. However, partisans of ready-made products will prefer to simply purchase a cord of firewood. Regardless of how one goes about it, one thing is certain, to get from a log to firewood, one must, among other things, split wood.

There are several types of hydraulic log splitters and the focus in this study will be on the vertical models. These systems can split logs 30 cm in diameter and 1 m in length and are designed using classical hydraulic principles, J.A Sullivan (1989), R. Labonville (1991) and H.E. Merritt (1993). Dimensions and choice of components must comply with current standards (Rabardel et al. 1998). Equipment must also comply with the act respecting occupational health and safety and be ergonomic.

In this case study, we will review the design of commonly used firewood splitters (see Figures 2-1 and 2-2). Our specific objectives are to:

- Conduct a conceptual study of the system and establish the dimensions of each of the components and structures used;
- Analyze and design a work station in accordance with occupational health and safety standards;
- Analyze and design a hydraulic system by assembling hydraulic power components.

2. Facts

2.1 Characteristics of a Log Splitter

A log splitter can operate at ambient temperatures varying between minus 25°C and 35°C and must be corrosion proof. The hydraulic and electric components are equipped with appropriate gasket joints. Log splitters must sometimes be carried to quite remote locations in the forests of Quebec and are usually kept in cramped spaces (1 m by 1 m by 1½ m). More often than not, the ground on which they are set is hilly, so the equipment structure must be robust and able to maintain secure footing to ensure stability when in use.

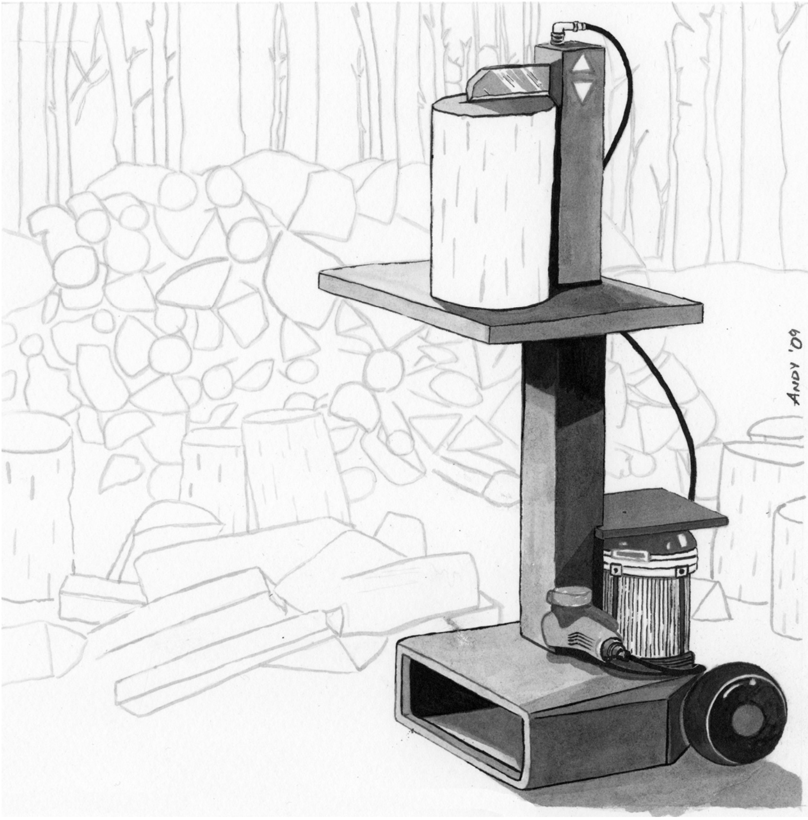

Figure 2-1: Log splitter – compact model

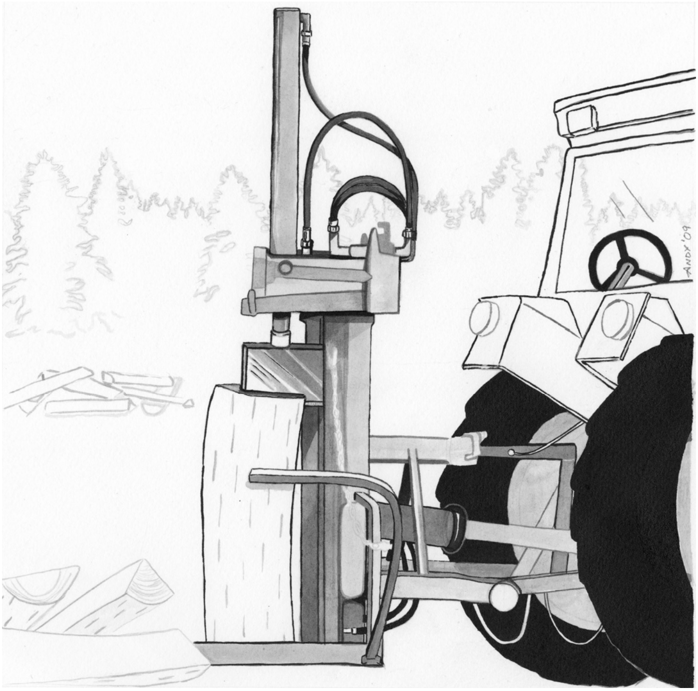

Figure 2-2: Log splitter – high power model

The equipment travels along a controlled trajectory. The control panel includes among other things a start button, an emergency stop button, a control device and a safety mechanism.

3. Questions

After having carefully researched all the log splitters available on the market and having become aware of the problem stated in this case study, you are asked to re-engineer a log splitter, in view of improving the following aspects: hydraulics, strength of materials and occupational health and safety. The design solution you propose for the log splitter must be inexpensive given that potential clients for this type of equipment operate on modest budgets.

The best solution will be studied in greater detail as to the following aspects:

3.1 Strength of Materials

You are asked to establish the dimensions of the log splitter of your choice and provide detailed calculations. You must design the base and main structure of the splitter and make all necessary structural calculations, select the primary hydraulic and electric components (motor, pump, cylinder and tank) and calculate the power requirement.

Once this has been completed, use a general purpose finite elements software to model the log splitter structure for the purpose of analyzing the strength of the structure under different operating conditions for example, the machine falls over on a hill, or off a truck during transportation.

In comparison with the two systems described above and the other types of splitters available on the market, suggest an alternative which you consider better, based on your own set of criteria.

3.2 Hydraulic and Pneumatic Control Systems

It is required to design a hydraulic system and select components taking into account the pressure loss in the hydraulic circuit and accessories. Study the dynamic aspects and estimate the time required to split a specific number of logs. Calculate the energy efficiency of the system and, if needed, optimize the resulting solution. Finally, simulate the hydraulic system using a software program of your choice.

3.3 Ergonomics and Occupational Safety

Make recommendations as to the ergonomics and safety of the splitter. More specifically:

- Using a causal tree, define 5 possible injuries.
- Once the causal tree is completed, validate your observations by referring to the articles from the regulation on occupational health and safety that are relevant to your design.
- Design the log splitter's work table position to facilitate the worker's task of manually loading the splitter.
- Design a control panel which takes into account the following indicators and actuators:

Table 2-1: Control panel component according to their level of importance

Component	Level of importance (1-10)
Light indicator during log splitter blade descent	**9**
Light indicator when log splitter is powered on	**3**
Light indicator to show status of blade safety breaks	**6**
Actuator for vertical displacement of blade (up / down)	**7**
Emergency stop button	**10**
Splitter start / stop pushbutton	**4**
Light indicator: small light. **Actuator**: Joystick, pushbutton, roller, lever, to choose from and justify your choice.	

Determine the dimensions and type of indicator and justify your choice. Position the actuators and determine their specifications (dimensions, colour, activation mode, etc.).

As an engineer working for a company owning a log splitter similar to the one shown in figure 2-1, you are asked to investigate a reported accident, which has occurred while using this machine. Here is a summary of the event:

Mr. T was in a hurry to split a few logs because he had a busy day ahead of him. It was the morning after a rainy night, and because the pile of wood was not properly covered, the logs were soaked. Mr. T knew that the log might slip, so he attempted to secure it with one hand while the other activated the “on” switch. His grip on the log was not strong enough, so the log slipped and flew violently out of place, hitting Mr. T on the head and twisting his wrist.

Do you think the product should be recalled by the company and modified? What corrective solutions can you suggest to prevent this type of accident from occurring again? Note that for any modifications to the existing product, cost and facility of implementation are key factors.

Is this accident exclusively a result of misuse and carelessness? What precautions should have been considered when the product was first designed?

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References

Department of Defense, «Design Criteria Standard Human Engineering, MIL-STD-1472F», États-Unis. [Internet]. Available from: http://hfetag.dtic.mil/docs/mil-std-1472f.pdf. http://www.inrs.fr/produits/publications.pdf/ed807.pdf.

Labonville, R. Concepts des circuits hydrauliques : une approche énergétique, Éditions de l'École Polytechnique de Montréal, 1991.

Lupin, H. et Marsot, J. (2000). « *Sécurité des machines et des équipements de travail. Moyens de protection contre les risques mécaniques* ». Édition INRS ED 807, France. [Internet]. Access:

Merritt, H.E. Hydraulic Control Systems, John Willey & Sons, New York, 1993.

Rabardel, P., Carlin, N., Chesnais, M., Lang, N., Le Joliff, G. et Pascal, M. Ergonomie concepts et méthodes, Éditions Octares, France, 1998.

Regulation on occupational health and safety. S-2.1, r.19.01. [Internet]. Available from: http://www.csst.qc.ca/pdf/RSST.pdf.

Sullivan, J.A. Fluid Power System: Theory and Applications, 3rd edition, Englewood Cliffs, New Jersey, 1989.

The *Act Respecting Occupational Health and Safety*, R.S.Q., Chapter S-2.1. [Internet]. Available from: http://doc.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=/S_2_1/S2_1.html or http://www.csst.qc.ca/fr/14_lois_et_regl/141_lois/1412_sst/sst.asp.

CHAPTER THREE

CASE STUDY: JEWELS OF TASMANIA

B. ATEME-NGUEMA

Summary

Designing flexible manufacturing workshops, better known as flexible manufacturing cells, will be the focus of this case study. By using a case study format, problems relating to the design, management and installation of a manufacturing system will enable engineering and management students to work on multidisciplinary projects for which integration of knowledge from operations and production management, industrial engineering and occupational health and safety will be essential. Considering the interconnectedness of these fields is part of the approach used to solve problems presented in this case. As well, information gathered and the work hypotheses formulated will enable professors to prepare projects or case studies.

Keywords: Manufacturing systems, industrial engineering, operations and production management and occupational, health and safety

1. Context

In Dover, on the Island of Tasmania, Australia, a company named *Jewels of Tasmania* manufactures nine types of golden wooden toys. Since the beginning of the last century, the colour "gold" has become time-honoured and can be obtained from high quality graphite mined in China, where the colour gold symbolizes excellence and royalty.

Table 3-1: Description of the *Jewels of Tasmania* products

Toys Manufactured	Description	Target market
18au19b	Quality wooden toys come with a graphite pencil and eraser (For example: slate board on stand with pencil, etc.)	Europe
315-bdc		
42161-4		
13sh333		
23336-2	Toys intended for popular North-American market (For example: musical mobiles, lamps, small cars, puzzles, etc.)	North America
42255-3		
461-cae		
12sh333	Wooden toys for local market (For example: wooden toys that are small and varied)	Australia
15sh333		

The company *Jewels of Tasmania* manufactures toys of which certain models prized in Europe come with a graphite pencil tipped with an eraser. The models "*18au19b*", "*315-bdc*", "*42161-4*" and "*13sh333*" are particularly in demand and intended for a wealthy European market with high standards. For the North-American market, *Jewels of Tasmania* offers models "*23336-2*", "*42255-3"* and "*461-cae*", which are all-purpose toys one can find in typical stores intended for the general population. For local sales, *Jewels of Tasmania* proposes models "*12sh333*" and "*15sh333"*.

For toys intended for the European market, *Jewels of Tasmania* decided to include a pencil for which the lead is made of a combination of graphite and clay, balancing hardness and blackness to achieve the desired line. In its choice of wood for its toys, *Jewels of Tasmania* employs cedar, maple, birch and ozigo. These four wood essences can be easily cut into thin slats and milled, for instance. The wood suppliers of the *Jewels of Tasmania* guarantee an ample supply of maple and cedar in exchange for a minimal order. The birch is from Canada and the ozigo is from Gabon, Africa. The latter essence is employed for toys intended for the European market, since it confers to the toy and its accompanying pencil an air of luxury and a high quality finish in addition to its good adhesion to the writing core. Note that these essences are not known to cause splinters.

For all its toys, *Jewels of Tasmania* purchases wood that is already cut into blocks. The blocks are cut with precision into thin slats and then placed into a vat to soak an emollient stain. For toys intended for the European market, circular grooves are cut lengthwise into one surface of the slats. Rods of graphite/clay are inserted into the grooves. Then glue is applied to the slat, a second grooved slat is aligned to the first and they are pressed together to encase the writing core. The glued slats are then cut into individual sticks and the ends are trimmed to the standard pencil length. The pencils for European toys are then polished, painted and set to dry. On one end of the pencil a ferrule is glued, clamped and fitted with an eraser held in place by embossing the ferrule. To finish, all the toys are packed and placed into cardboard boxes fitting 25 units. All these operations are automated.

Jewels of Tasmania sells its products in cardboard boxes. For the next production lots, ecologists have expressed that industries manufacturing various wood products contribute to irresponsible over-logging by African foresters, particularly the ozigo species for which no effort is made to renew this resource. In light of this, *Jewels of Tasmania* wishes to take this into consideration and reduce, if possible, its production of luxury toys made with ozigo. The projected sales for the company are:

Table 3-2: Projected sales for the 1st year

Months	Number of toys to be manufactured									
	18au19b	315-bdc	42161-4	13sh333	23336-2	42255-3	461-cae	12sh333	15sh333	# days
January	3 000	2 225	4 332	1 332	1 343	1 009	1 103	110	113	22
February	3 000	3 400	1 210	996	1 115	2 080	783	151	55	21
March	4 000	3 050	6 111	3 133	5 111	17	1 044	104	98	20
April	5 000	1 775	7 012	3 201	3 012	1 105	203	203	101	21
May	5 000	4 125	2 337	1 773	2 337	452	408	122	75	20
June	8 000	6 778	6 667	5 418	1 667	2 031	904	125	202	21
July	6 000	5 000	3 823	1 227	1 125	2 009	217	210	100	17
August	3 000	1 115	2 115	1 773	2 005	49	811	181	27	21
September	4 000	3 075	2 373	1 657	2 376	1 082	247	274	96	22
October	3 000	2 850	4 016	2 098	1 016	919	503	301	173	21
November	3 000	2 125	3 377	1 337	377	167	694	121	70	22
December	3 000	3 010	4 193	3 996	193	702	852	207	83	22
Total	50 000	38 528	47 566	27 941	21 677	11 572	7 769	2 109	1 193	250

Table 3-3: Projected sales for the 2nd year

Months	Number of toys to be manufactured									
	18au19b	315-bdc	42161-4	13sh333	23336-2	42255-3	461-cae	12sh333	15sh333	# days
January	3 003	2 222	4 932	1 302	2 443	110	1 778	176	131	22
February	3 666	3 250	5 100	1 801	1 694	321	1 302	190	545	21
March	4 333	4 950	3 111	3 872	5 111	121	1 414	151	9	20
April	5 666	4 333	3 012	4 104	3 012	257	655	227	101	21
May	6 333	7 005	4 337	6 206	2 337	167	890	174	7	20
June	8 666	7 950	3 667	1 708	1 667	2 011	1 101	331	22	21
July	7 500	3 980	6 823	1 562	1 125	1 103	711	616	100	17
August	3 666	2 975	4 115	1 909	2 005	2 943	1 180	130	27	21
September	4 000	1 225	6 373	2 401	2 373	693	1 427	292	96	22
October	5 000	6 800	4 016	2 983	3 012	393	802	252	17	21
November	4 333	1 111	5 377	2 807	798	1 099	964	161	170	22
December	5 000	1 210	7 193	4 045	1 089	1 002	1 208	217	363	22
Total	61 166	47 011	58 056	34 700	26 666	10 220	13 432	2 916	1 588	250