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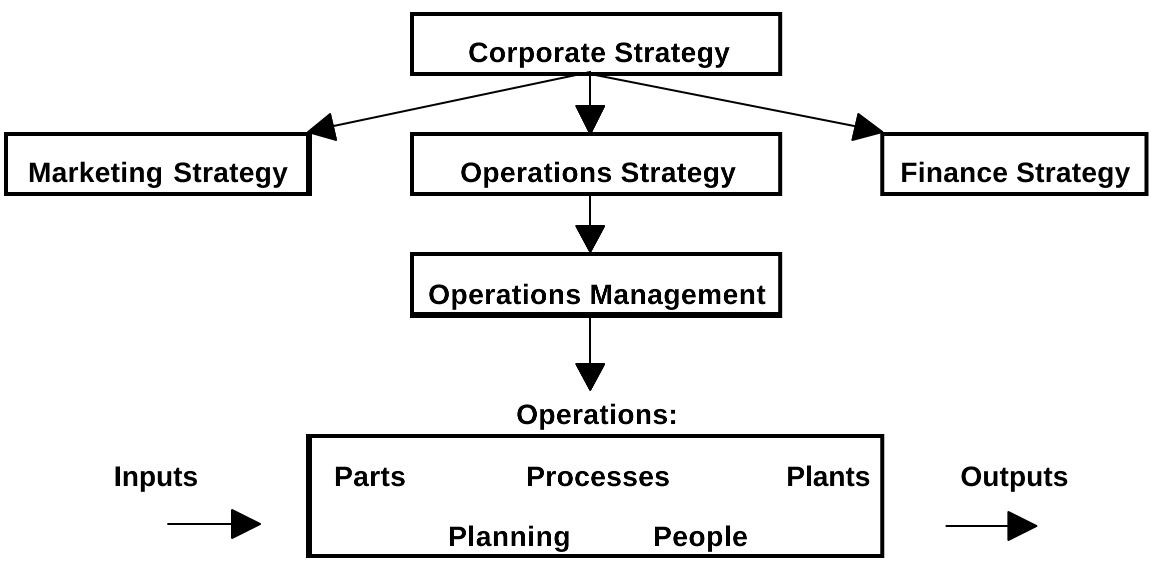
INTRODUCTION

What is Operations Management?

Operations Management is a functional field of business as are marketing, finance, accounting and human resource management (see chart below). It may be defined as the design, operation, and improvement of the systems that create the firm's products and services. For Boeing, that system is concerned with building airplanes and for Air Canada it is concerned with transporting people from city to city in an efficient and timely manner.



Operations Management uses the five **P's** : **p**eople, **p**lants, **p**arts, **p**rocesses, and **p**lanning and control to change inputs into outputs for the firm. How does ***Burger King*** use these elements to transform ground beef, buns, tomatoes, lettuce, mayonnaise, etc., into one of their famous *Whoppers*? How does their process differ from that of ***McDonald's***? Firms such as these two produce both **goods and services** but are usually classified as being in the service business because of the high level of interaction with their customers.

History

For as long as goods and services have been produced there have been managers in charge of overseeing those operations. The builders of the pyramids in ancient Egypt must have included operations managers, although they didn't know that's what they were, as the term had not been coined yet (not that we advocate slavery as a means to improve operational efficiency!). The formal study of operations management has its roots in the scientific management studies of Frederick W. Taylor in the early part of this century. Though often scorned today, his **time and motion studies** were the first serious study of the principles underlying the production of goods and services. His work and that of co-workers Frank and Lillian Gilbreth and Henry L. Gantt (we will hear more from him later in the course!) and later, Elton Mayo (you may have read about his famous *Hawthorne* studies in an organizational behavior course) were the beginnings of what we do in a modern business school. This work coincided with the development of Henry Ford's assembly line and the manufacturing revolution that followed.

World War II brought a new scale to *operations* management problems and with them the birth of a new discipline, **Operations Research**. OR, or **Management Science** as it is often called when applied to business problems, brings specialists in diverse fields such as mathematics, psychology and economics together to solve complex systems problems such as how to design, staff and operate a set of toll booths on a busy commuter highway so as to minimize operating cost and traffic delays. We will use many of the techniques developed in this field such as linear programming, inventory control, queuing theory and PERT/CPM in our study of operations management.

The 1980's and 90's have seen a new revolution in the practice and role of operations management. First, the Japanese demonstrated the competitive advantages that can come from the careful application of some new techniques; just-in-time production (**JIT**), computer-integrated production (**CIM**), and flexible manufacturing (**FMS**), and some old ones, most notably total quality management (**TQM**). Then a group of operations management researchers at the Harvard Business School (Skinner, Clark (the current Dean of HBS), Hayes, Wheelwright and Abernathy) demonstrated that the underlying principle behind all of these successful Japanese methods was the proactive, as opposed to reactive, role that operations played in the development of a firm's business strategy.

Contemporary opportunities and challenges facing operations managers include:

- Extracting value out of the ever-increasing amounts of data collected by businesses nowadays. Fortunately, the "information revolution" has not only made it easier to collect data but also to process it intelligently. Today's spreadsheets have built-in tools that only a few years ago required highly-trained and expensive specialists for successful application.
- Adapting the tools of the field, many of which were developed in manufacturing, to the increasingly important services sector. At the beginning of this century, 7 out of 10 workers in industrialized countries were employed in manufacturing. As we near the end of the century, more than 7 out of 10 workers in Canada are employed in various kinds of service organizations, ranging from fast-food outlets to management consulting firms.

Operations Strategy

Firms can be classified on a four point scale depending on the degree to which their operations (manufacturing or provision of services) play a role in the strategy of the organization. In the following table, these four stages are shown along with manifestations of each level from manufacturing and service firms. The theory of Hayes and Wheelwright ("Competing Through Manufacturing", *Harvard Business Review, 1985)* is that the more successful firms operate closer to stage IV.

	... in plain English	*How to do it in manufacturing*	*How to do it in services*
Stage I: **Internally neutral**	Don't screw up!	Use internal measures to monitor operations performance.	Keep costs down.
Stage II: **Externally neutral**	Keep up with the competitors!	Follow but don't lead industry in adoption of new technology.	Meet industry-wide customer expectations.
Stage III: **Internally supportive**	Be consistent with corporate strategy.	Choose technology and processes to support corporate objectives.	Exceed customer expectations.
Stage IV: **Externally supportive**	Be the basis for competitive advantage.	Develop innovative products and ways to make them.	Raise customer expectations.

Firms in Stage IV operate in a manner that those of us in Edmonton who watched #99 in the 1980's were very familiar with: ***they change the way the game is played and they always know where the puck is going before it gets there!***

Dimensions of Competition

There are four dimensions on which firms usually compete:

1. **Cost** – in many industries where there is little to distinguish one good or service from another the winner is the firm which keeps its costs of production the lowest.
2. **Quality** – in many markets, the customers are willing to pay for a product or service which works in the way they expect it to in an unfailing manner.
3. **Speed of Delivery** – often the winning firm is the one which can get its goods into the hands of the customer before others. This is often especially important for industrial customers (and Armann when he orders pizza after again forgetting to plan for dinner!).
4. **Flexibility** – the ability of a firm to tailor its products and services to the needs of the individual customer and to make last minute revisions is important in some markets and to some customers.

Today a firm often has to be good on most of these dimensions but most successful firms pick some dimensions to excel at and make necessary sacrifices on the others. For example, McDonald's has been highly successful in focusing on the first three, partly by deliberately sacrificing the fourth - they kept their menu small and allowed no variation in their food items. Some competitors make sacrifices on the first three to offer you your 'burger "... *any way you want it*." Can you think of some other examples? How about Fed-Ex, Wal-Mart, a local manufacturer of custom-made carbon fibre bikes? On which dimensions do they excel?

What Follows

In this course, we will look at how firms can analyze and make decisions on several operations issues so as to do well on the dimensions of competition. We begin with a look at business **Forecasting**. In order to make good operations decisions, a manager has to be able to predict what is going to happen tomorrow in an environment that is almost always changing. Most often this translates into a prediction as to what the demand will be for the firm's products or services. Only with a handle on this can planning and decision-making proceed.

Aggregate Planning comes next. Over the next 2 to 18 months, how can the firm best utilize the resources that it currently has available (long range planning deals with changing that resource base) so as to profitably meet predicted demand. Once this plan is in place, then weekly, daily and even hourly plans can be developed to carry out the firm's operations. These plans often deal with production schedules, deployment of manpower and purchasing decisions.

The amount of finished goods and raw materials that a firm has in stock is often a critical variable in the efficiency of the production process and this is the next topic in the course. Our look at **Inventory Control** also includes a demonstration of the impact that Japanese manufacturing techniques such as **JIT** can have on production processes.

The **Distribution** of goods and services to the customer in a timely and efficient manner is an area of increasing competitive importance. We will look in particular at the optimization of transportation networks using techniques that are heavily used in industry today.

In a world of rapidly changing markets, project teams are often the means of getting a product to market in a timely and quality driven fashion (*please* don't ask the Professor to explain how these principles were applied to the building of the new computer lab in the basement of the business building!). **Project Planning** using critical path methods is a topic that we undertake near the end of the course.

In almost all service firms, **Managing Congestion** is a key operations issue. To make money, a firm must be able to serve a large number of customers with as few employees as it can, but the balance is delicate. Too few servers and the lines grow long and the customers don't come back (or worse yet, they leave before buying). Just like in our discussion of inventory policies, variability and randomness will prove to be a confounding but not insurmountable problem in our staffing decisions.

Modeling

A **model** is a selective abstraction of reality. (e.g. model airplane, schematic diagram, Claudia Schiffer)

- often more useful for a particular purpose than the real thing. This is how models should be judged.

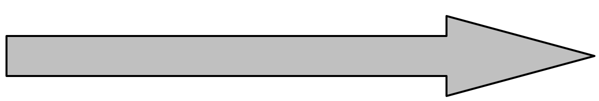
Spreadsheet (algebraic) models of decisions

- define decision cells (variables)
- express relations between cells (equations)

Why model?

- provides a precise and concise problem statement
- establishes what data are necessary for decision
- clarifies relationships between decision variables
- enables the use of known solution methods, "algorithms"

Tradeoff between realism and usefulness (complexity, data requirements, computational requirements)

Simple  **Complex**

Criterion:

Does the model predict the relative effects of alternative courses of action with sufficient accuracy?

- Models are **tools** in decision-making.
  They **do not** replace the human decision-maker (qualitative considerations, experience, selective abstraction, ...).
- **GIGO**! Printouts may look awfully fancy, but ..
- Analysis before and **after** the solution
- Carefully state your assumptions
- Carefully define your notation
- Consider data availability

Problem Solving

-- where does modeling fit in the problem solving process?

Steps in problem solving:

1. Problem Formulation: Textbooks deliver the formulation in a compact and precise form. However, this is the most difficult phase in the real world. It requires "living" with the problem.

- What is the objective?
- Whose objective is that?
- Who are the decision-makers?
- What are the priorities?
- What are the solution alternatives?
- What are the restrictions (rules, constraints)?

2. Modeling

3. Solution: Selecting one of the alternative courses of action. This phase includes post-optimality (sensitivity, robustness) analysis: What happens when we change the parameters of the model?

- The solution of a model is the solution of a model.
- "Optimal" is a mathematical term.

4. Testing the Model/Solution

- Verification of the model (model vs. computer program)
- Validation of the model (model vs. real-world)

5. Establishing Controls over the Solution:

Systematic procedures to detect change, so we know when the model is not valid anymore.

6. Implementation

- A good decision does not imply a good outcome.
- The use of management science does not guarantee success. However, in the long run, a decision-maker is much better off **with** models than without models.

FORECASTING

(**Note**: I highly recommend that you also take a look at the on-line version of the lecture notes for Forecasting which is available through the course web. The on-line version allows you to download every spreadsheet shown. Also, it has some interactive features, and it gives additional details on some topics.)

Background

Forecasting means to predict what will happen in the future. Thus, it includes anything from a fortune teller gazing into a crystal ball to economists developing sophisticated computer models to predict the future course of national economies or meteorologists predicting the weather. None of these are easy tasks, and forecasts are often far off the mark, regardless of the sophistication of the forecaster. Nevertheless, we all continue to forecast:

- Students try to forecast what questions will be asked on an exam and study accordingly
- Hockey fanatics predict which teams will be most successful and play hockey pools accordingly
- Party planners try to estimate how many will come to a party and how much they will eat and drink and purchase food and drink accordingly.

The common element here is that forecasts are the basis for planning.

We will concentrate on a particular kind of forecasting, namely demand forecasting, whereby a business attempts to predict how many people will want to purchase its product or service in future time periods. The basis for such forecasts could be the subjective judgment of managers or experts, market surveys, information about overall demand in the economy, or historical demand patterns. We will concentrate on the last category – the extrapolation of historical demand patterns into the future. Such forecasts are called time-series forecasts and are based on the assumption that the conditions that caused past demand to be what it was will continue to prevail in the future. (Take MGTSC 405 if you want to learn about other forecasting methods.)

Demand forecasting is an ongoing function in all companies, whether this is formally recognized or not. Typically, the sequence of events is as follows:

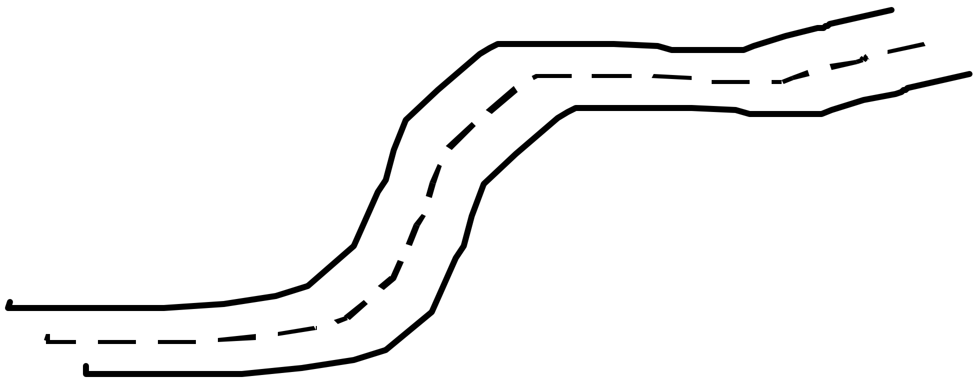
- Person responsible for forecasting (the forecaster) makes a forecast for a future time period, e.g., next quarter.

- Decisions are made based on the forecast, for example ordering of supplies or commitments to employees.
- Time passes and reality unfolds. The consequences of the forecast being different from reality occur. There may be consequences both to the company (excess inventory or stockout, over- or understaffing) and to the forecaster (bonuses or lack thereof).
- Data are recorded.
- The forecaster makes a new forecast for the next time period and the process repeats itself.

In this chapter, you will learn methods for demand forecasting and you will see some ways to quantify and minimize the undesirable consequences of forecast error. How to make decisions based on forecasts is the subject of later chapters.

Introduction to Forecasting

Forecasts provide a basis for planning. They predict the **future** (such as demand for a product) based on **past** results.



Fiedler's Forecasting Rule #1:
Forecasting is difficult, especially if it's about the future!

Rule #0: ***Every forecast is wrong!***

Forecasting is used at many levels:

- Technological forecast
- Economic forecast
- Demand forecast
    - ∗ Aggregate demand (long term strategic plans)
    - ∗ Item forecast (for inventory, prod'n planning)

Methods of Forecasting

Qualitative methods

- **The Delphi Technique** is a common example: in it, expert opinions are pooled to produce a forecast of upcoming events.

Quantitative methods

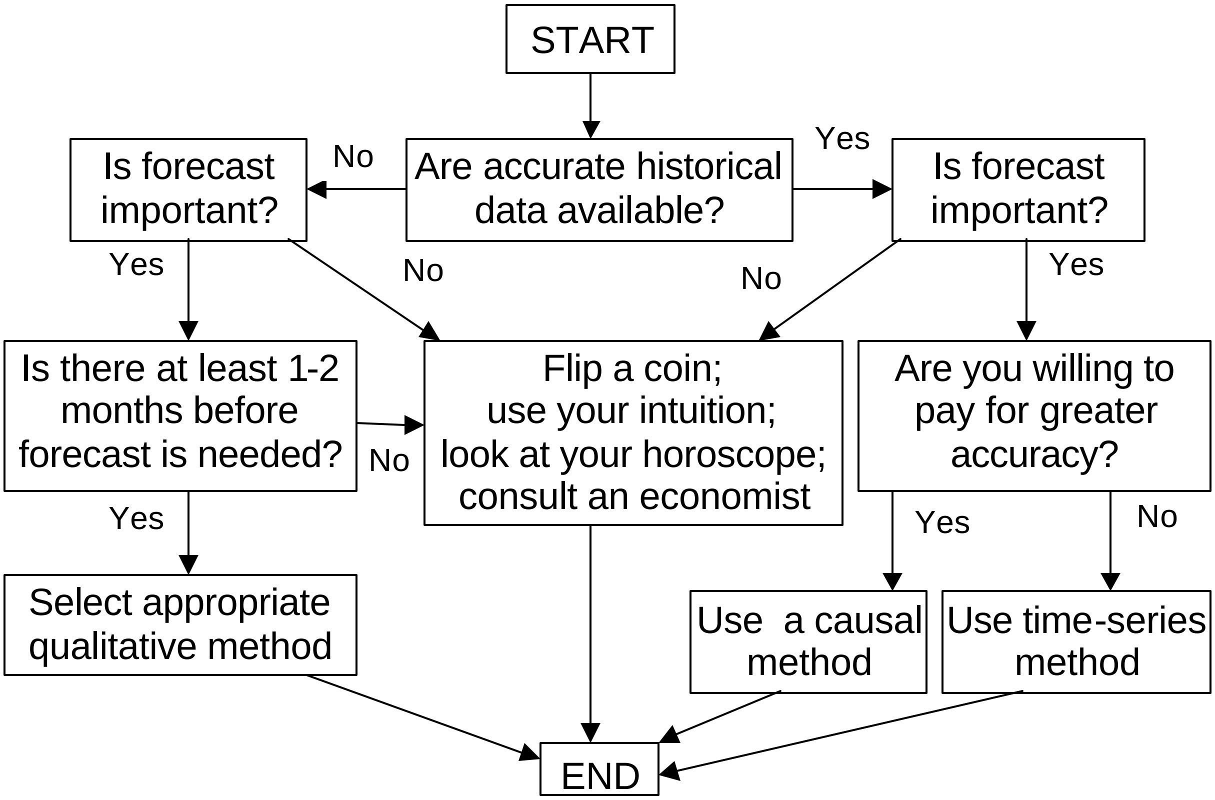
- **Time series analysis**: uses only past records of demand to forecast future demand. (Examples: moving averages, exponential smoothing, Box-Jenkins)
- **Causal methods**: use additional “explanatory variables,” e.g., the timing of advertising campaigns, price changes, etc. (Examples: multiple regression, econometric models)

Selection Criteria

Determine which forecasting method to use based on:

- Forecast horizon
- Required accuracy
- Data availability
- Constraints

Selecting a forecasting method



Simple vs. complex models: Complex models require more data and more effort than simple models. However, they are not always more accurate than simple models.

Start simple. Complicate only if necessary! ☠

Time Series Analysis

Components of a time series:

- level
- trend
- seasonality
- cyclic (we will ignore this)
- random

Notation:

D_t = Actual demand in time period t
(“period” could be week, month, quarter, etc.)

F_t = Forecast for period t

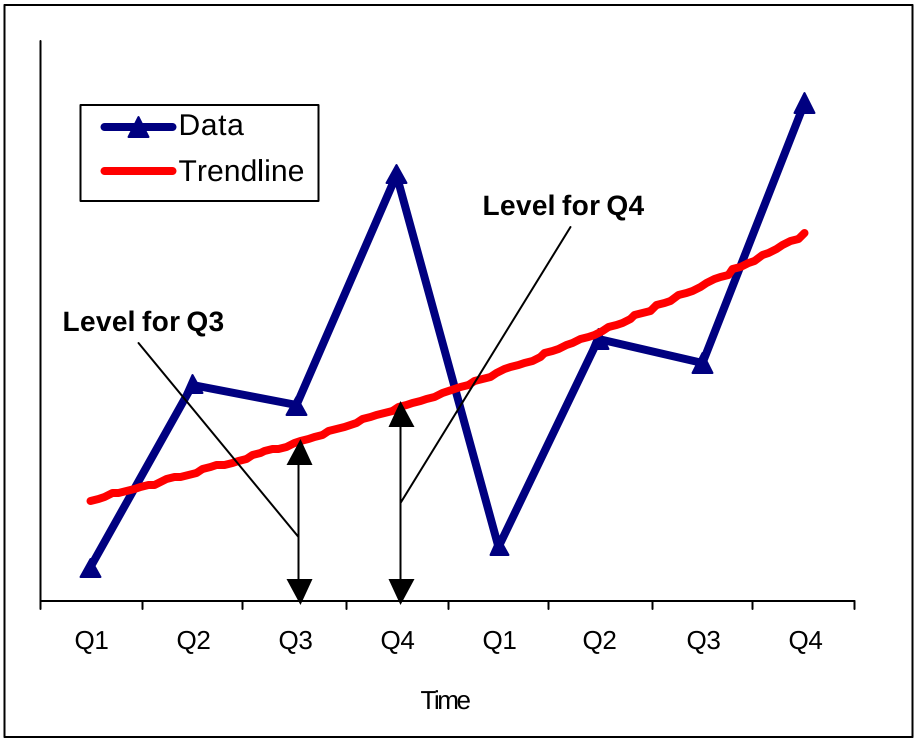
$E_t = D_t - F_t$ = Forecast error for period t
(how far off the forecast turns out to be)

Decomposition of a time series:

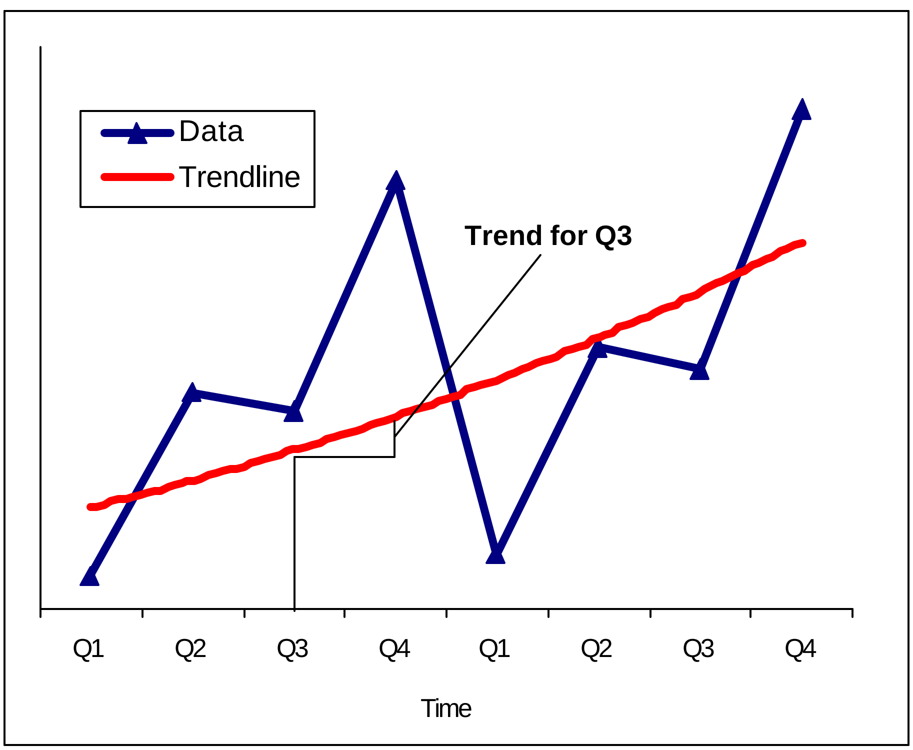
D(t) = Level(t)*Seasonal Index(t) + Random Error(t)

Level(t+1) = Level(t) + Trend(t)

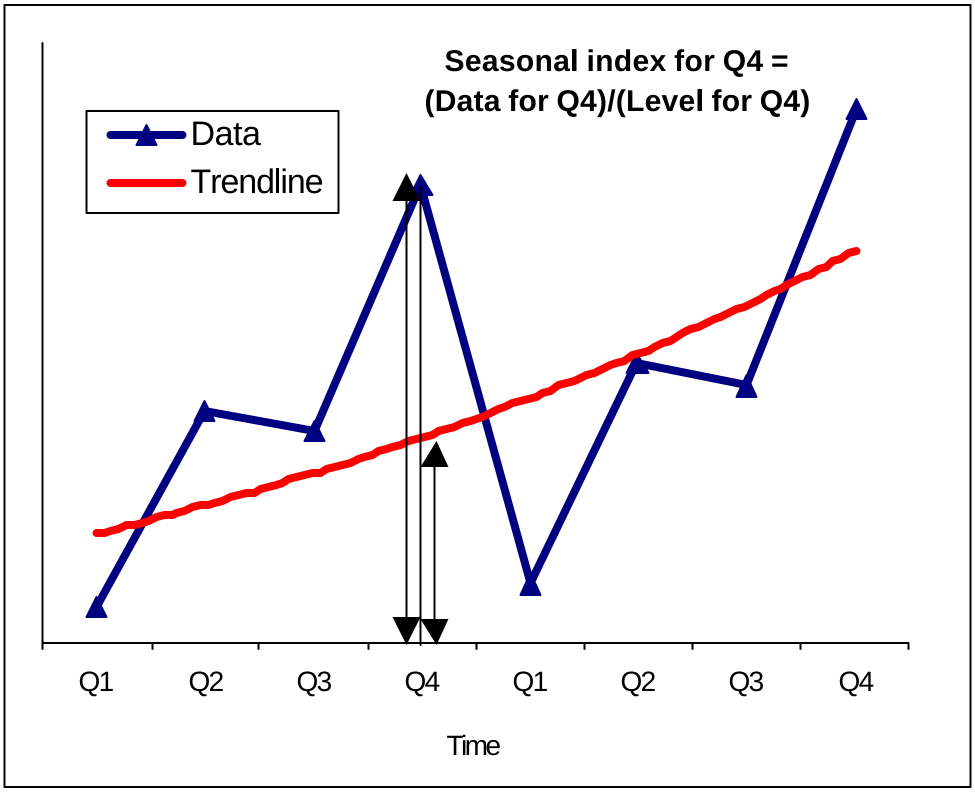
What is "Level?"



What is "Trend?"



What is "Seasonal Index?"



Simple Time Series Models

Given the following sales data, what is your sales forecast for month 7?

Monthly Sales Data					
D_1	D_2	D_3	D_4	D_5	D_6
60	65	55	70	62	66

Model 0 (LP): F_7 =

Model 1 (Avg.): F_7 =

Model 2 (SMA): F_7 =

Model 3 (WMA): F_7 =

Model 4 (ES): $F_{t+1} = (LS)D_t + (1-LS)F_t$ where $0<LS<1$.

[Equivalently: $F_{t+1} = F_t + LS(D_t - F_t)$

Suppose LS = 0.25:

Month	Demand	Forecast	Error
1	60.00	60.00	0.00
2	65.00	60.00	5.00
3	55.00	61.25	-6.25
4	70.00	59.69	10.31
5	62.00	62.27	-0.27
6	66.00	62.20	3.80
7		63.15	

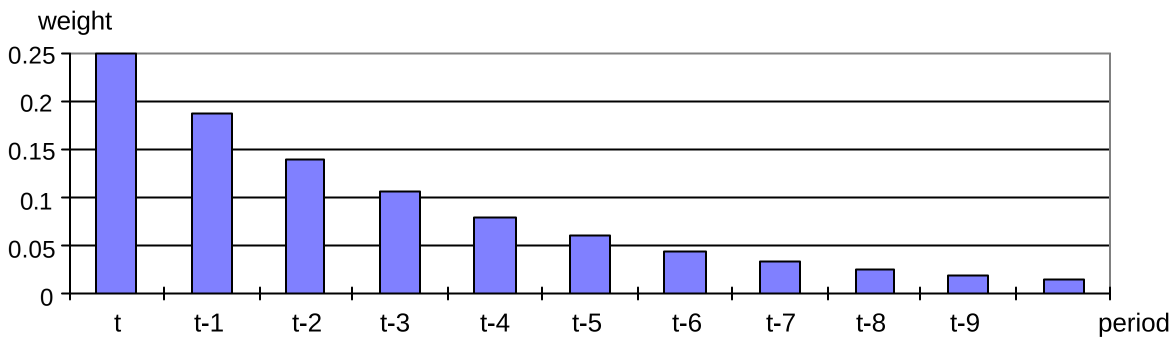
More on Exponential Smoothing

ES takes all of the past data into account.

$F_{t+1} = (LS)D_t + (1-LS)F_t\ =$

LS = 0.25

Period	t	t-1	t-2	t-3	t-4	t-5	t-6	t-7	t-8	t-9	…
Weight	0.25	0.19	0.14	0.11	0.08	0.06	0.04	0.03	0.03	0.02	…



⇒An exponentially smoothed forecast is really a weighted average, with the weights getting smaller and smaller for demand that is further and further in the past.

How does one choose the **smoothing** parameter LS?

The **responsiveness** of the model depends on LS: the higher the value of LS the more the model considers new data and discounts past data. With an LS of 1, the model is simply a last period forecast.

Performance measures can help in selecting a value for LS (see next page).

Performance Measures

A “good” forecasting method results in “small” errors.

Performance measures summarize the performance of a forecasting method over many periods.

Five common measures are listed below.
(n = the number of data points)

BIAS (average error): $\frac{1}{n}\sum_{t=1}^{n} E_t$

MAD (mean absolute deviation): $\frac{1}{n}\sum_{t=1}^{n} |E_t|$

SE (standard error): $\sqrt{\frac{1}{n-1}\sum_{t=1}^{n} E_t^2}$

MSE (mean square error): $SE^2 = \frac{1}{n-1}\sum_{t=1}^{n} E_t^2$

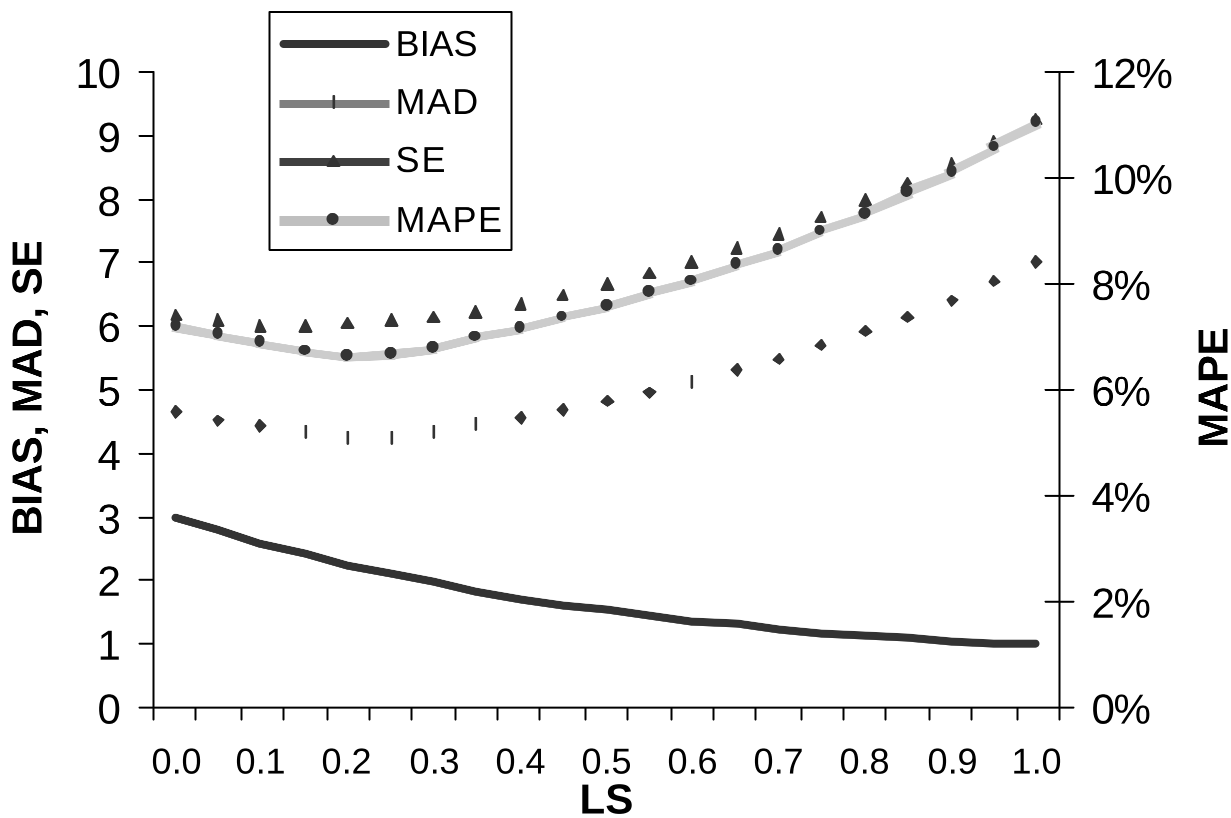
MAPE (mean abs. percent error): $\frac{1}{n}\sum_{t=1}^{n} |E_t / D_t|$

- BIAS can be negative or positive and is a measure of how “centered” the forecasts are. Others are always positive and measure how close to actual demand the forecasts are.
- BIAS, MAD, and SE have the same unit as the actual demand. The unit of MSE is the unit of the actual demand squared; this makes MSE difficult to interpret. The units of MAPE are percentages.

Using Performance Measures

The following example shows how performance measures can be used to "tune" a forecasting method.

	A	B	C	D	E	F	G	H	I
1	**Sales**	**Forecast**	**Error**	**Abs. error**	**Sq. error**	**Abs. % error**		**LS**	**0.3**
2	60	60.00	0.00	0.00	0.00	0%			
3	65	60.00	5.00	5.00	25.00	8%		**BIAS**	1.96
4	55	61.50	-6.50	6.50	42.25	12%		**MAD**	4.36
5	70	59.55	10.45	10.45	109.20	15%		**MSE**	37.86
6	62	62.69	-0.68	0.68	0.47	1%		**SE**	6.153
7	66	62.48	3.52	3.52	12.39	5%		**MAPE**	7%
8		63.54							

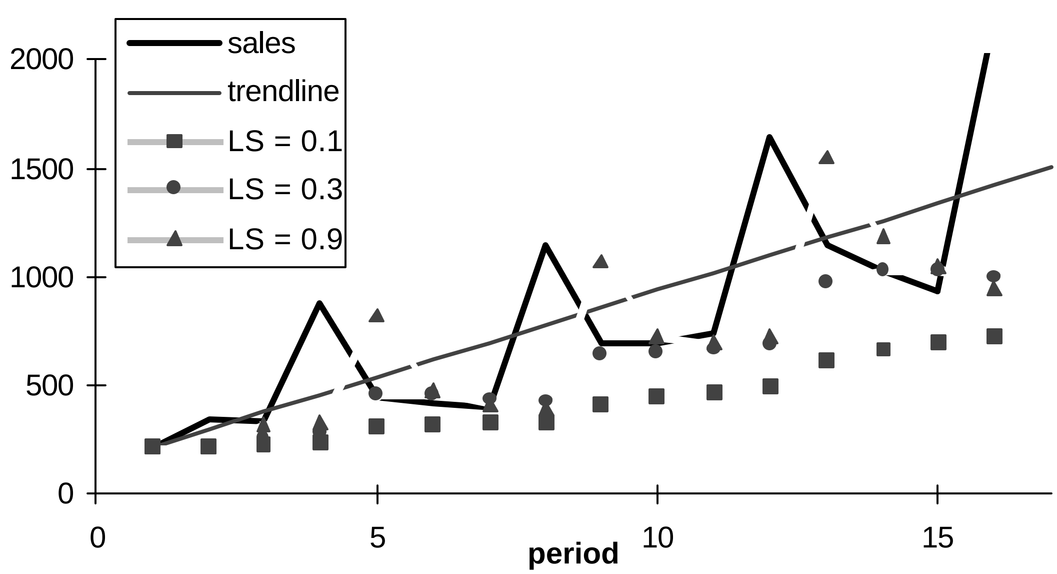


The sample size (the number of periods) is very small. Values of LS greater than 0.3 may cause the forecast to be too volatile.

Trend and Seasonality

Column D contains actual quarterly sales data for **Country Greeting Cards** for the past 4 years. They would like to forecast sales for the upcoming year, year 5. It is currently the beginning of period 17. Columns F,G and H contain attempts to use **exponential smoothing**.

	A	B	C	D	E	F	G	H
1	**Country Greeting Cards:**				**LS =**	0.1	0.3	0.9
2	**year**	**quarter**	**period**	**sales**	**trend**	**ES1**	**ES2**	**ES3**
3	1	1	1	222	221	222	222	222
4		2	2	339	301	222	222	222
5		3	3	336	381	234	257	327
6		4	4	878	462	244	281	335
7	2	1	5	443	542	307	460	824
8		2	6	413	622	321	455	481
9		3	7	398	703	330	442	420
10		4	8	1143	783	337	429	400
11	3	1	9	695	863	418	643	1069
12		2	10	698	944	445	659	732
13		3	11	737	1024	471	671	701
14		4	12	1648	1104	497	690	733
15	4	1	13	1141	1185	612	978	1557
16		2	14	1036	1265	665	1027	1183
17		3	15	938	1345	702	1029	1051
18		4	16	2168	1426	726	1002	949
19	5	1	17		1506			



Triple Exponential Smoothing (TES)

Winters' Trend and Seasonality Model (1960)

The simple time series forecasting models essentially ignore the seasonality and trend in the series. However, exponential smoothing can be adapted to include these components of a time series pattern. The basic technique described here was developed by Winters. A number of other modifications of exponential smoothing exist that are able to handle these components, but in practice it seems to make little difference which extension is used.

The basic idea is to smooth the **level**, the (additive) **trend** and the (multiplicative) **seasonal** components of the series. At time t the one-step forecast is

$$F_{t+1} = (L_t + T_t)\, S_{t+1-p}$$

where

L_t = level of the series at time t

T_t = trend at time t

S_{t+1-p} = seasonal factor at time (t+1-p),
(i.e., same time last year)

p = no. of seasons (12 months, 4 quarters, etc.)

A k-step forecast at time t is

$$F_{t+k} = (L_t + k\, T_t)\, S_{t+k-p}$$

Initialization in TES

For initialization, we describe a method that assumes only (p + 1) periods of past data: D_1, D_2, ..., D_{p+1}. Let A be the average of the data over the first p periods. Seasonality is initialized by:

$$S_i = \frac{D_i}{A} \text{ for } i = 1, 2, \ldots, p.$$

For example, $S_i = 1.25$ suggests that the corresponding season is 25% "higher" than average.

The trend is initialized by:

$$T_p = \frac{D_{p+1} - D_1}{p}$$

which is an estimate of the per period growth over the first p+1 observations.

The level is initialized by:

$$L_p = A$$

Updating in TES

At the end of period t (i.e., when D_t, the actual value of the forecasted series, becomes known), the estimates of the three components of the time series are updated as follows. (LS, TS, and SS are the smoothing constants for Level, Trend, and Seasonality respectively; all three are between 0 and 1.)

1. Update the level:

$$L_t = LS\frac{D_t}{S_{t-p}} + (1 - LS)(L_{t-1} + T_{t-1})$$

2. Update the trend:

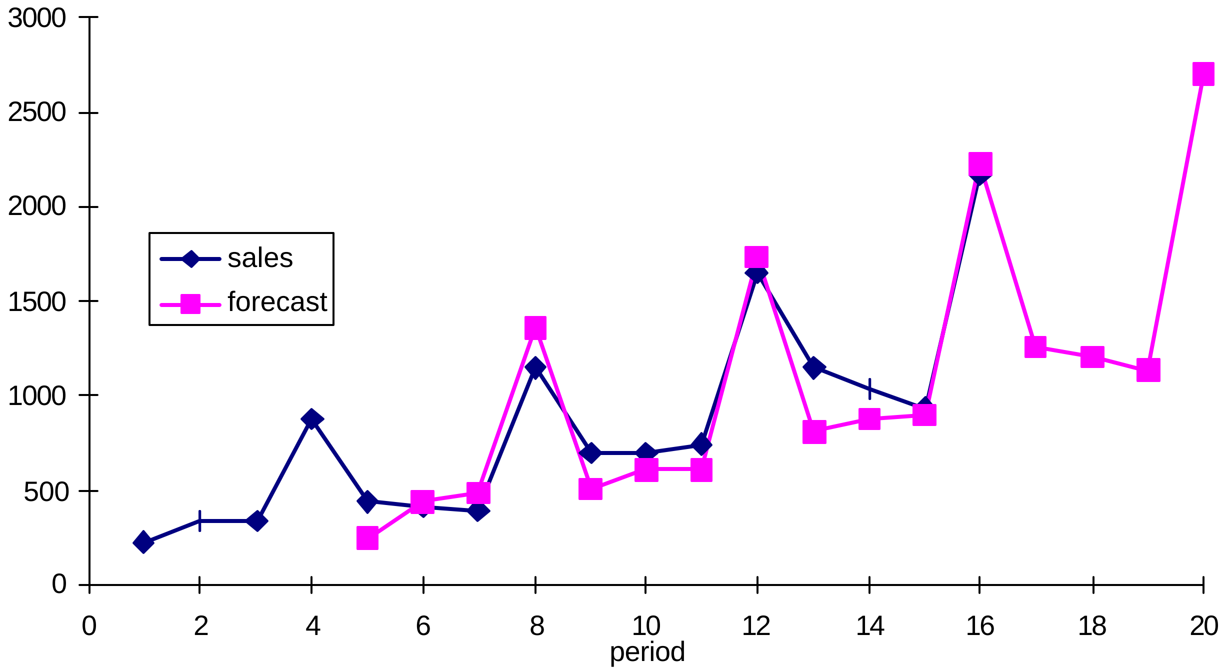
$$T_t = TS(L_t - L_{t-1}) + (1 - TS)T_{t-1}$$

3. Update the seasonality:

$$S_t = SS\frac{D_t}{L_t} + (1 - SS)S_{t-p}$$

Example (TES)

	A	B	C	D	E	F	G	H	I	J	K
1	**Country Greeting Cards:** ***Triple Exponential Smoothing***									**LS =**	**0.04**
2										**TS =**	**0.30**
3										**SS =**	**0.50**
4	**year**	**quarter**	**period**	**sales**	**forecast**	**level**	**trend**	**seasonal.**	**error**	**abs. error**	**% error**
5	1	1	1	222				0.50			
6		2	2	339				0.76			
7		3	3	336				0.76			
8		4	4	878		443.75	55.25	1.98			
9	2	1	5	443	249.64	514.46	59.89	0.68	193.36	193.36	43.6%
10		2	6	413	438.77	573.00	59.48	0.74	-25.77	25.77	6.2%
11		3	7	398	478.90	628.21	58.20	0.70	-80.90	80.90	20.3%
12		4	8	1143	1358.12	682.06	56.90	1.83	-215.12	215.12	18.8%
13	3	1	9	695	503.00	750.24	60.28	0.80	192.00	192.00	27.6%
14		2	10	698	601.69	815.71	61.84	0.80	96.31	96.31	13.8%
15		3	11	737	610.22	884.84	64.03	0.76	126.78	126.78	17.2%
16		4	12	1648	1733.77	946.99	63.46	1.78	-85.77	85.77	5.2%
17	4	1	13	1141	811.93	1026.83	68.38	0.96	329.07	329.07	28.8%
18		2	14	1036	875.10	1103.26	70.79	0.87	160.90	160.90	15.5%
19		3	15	938	897.15	1176.20	71.43	0.78	40.85	40.85	4.4%
20		4	16	2168	2225.43	1246.34	71.05	1.76	-57.43	57.43	2.6%
21	5	1	17		1261.21					**BIAS**	56.2
22		2	18		1206.59					**MAD**	133.7
23		3	19		1139.59					**MSE**	27235.3
24		4	20		2696.21					**MAPE**	17%



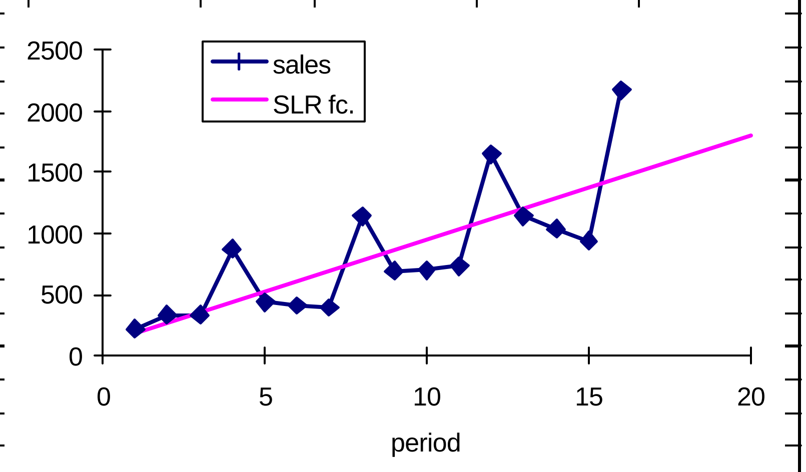
Spreadsheet formulae for TES example

	A	B	C	D	E	F	G	H	I	J	K
1	**Count**									**LS =**	0.04
2										**TS =**	0.3
3										**SS =**	0.5
4	**year**	**quarter**	**period**	**sales**	**forecast**	**level**	**trend**	**seasonal.**	**error**	**abs. error**	**% error**
5	1	1	1	222				=D5/F$8			
6		2	2	339				=D6/F$8			
7		3	3	336				=D7/F$8			
8		4	4	878		=AVERAGE(D5:D8)	=(D9-D5)/4	=D8/F$8			
9	2	1	5	443	=(F8+G8)*H5	=LS*(D9/H5)+(1-LS)*(F8+G8)	=TS*(F9-F8)+(1-TS)*G8	=SS*(D9/F9)+(1-SS)*H5	=D9-E9	=ABS(I9)	=J9/D9
10		2	6	413	=(F9+G9)*H6	=LS*(D10/H6)+(1-LS)*(F9+G9)	=TS*(F10-F9)+(1-TS)*G9	=SS*(D10/F10)+(1-SS)*H6	=D10-E10	=ABS(I10)	=J10/D10
11		3	7	398	=(F10+G10)*H7	=LS*(D11/H7)+(1-LS)*(F10+G10)	=TS*(F11-F10)+(1-TS)*G10	=SS*(D11/F11)+(1-SS)*H7	=D11-E11	=ABS(I11)	=J11/D11
12		4	8	1143	=(F11+G11)*H8	=LS*(D12/H8)+(1-LS)*(F11+G11)	=TS*(F12-F11)+(1-TS)*G11	=SS*(D12/F12)+(1-SS)*H8	=D12-E12	=ABS(I12)	=J12/D12
13	3	1	9	695	=(F12+G12)*H9	=LS*(D13/H9)+(1-LS)*(F12+G12)	=TS*(F13-F12)+(1-TS)*G12	=SS*(D13/F13)+(1-SS)*H9	=D13-E13	=ABS(I13)	=J13/D13
14		2	10	698	=(F13+G13)*H10	=LS*(D14/H10)+(1-LS)*(F13+G13)	=TS*(F14-F13)+(1-TS)*G13	=SS*(D14/F14)+(1-SS)*H10	=D14-E14	=ABS(I14)	=J14/D14
15		3	11	737	=(F14+G14)*H11	=LS*(D15/H11)+(1-LS)*(F14+G14)	=TS*(F15-F14)+(1-TS)*G14	=SS*(D15/F15)+(1-SS)*H11	=D15-E15	=ABS(I15)	=J15/D15
16		4	12	1648	=(F15+G15)*H12	=LS*(D16/H12)+(1-LS)*(F15+G15)	=TS*(F16-F15)+(1-TS)*G15	=SS*(D16/F16)+(1-SS)*H12	=D16-E16	=ABS(I16)	=J16/D16
17	4	1	13	1141	=(F16+G16)*H13	=LS*(D17/H13)+(1-LS)*(F16+G16)	=TS*(F17-F16)+(1-TS)*G16	=SS*(D17/F17)+(1-SS)*H13	=D17-E17	=ABS(I17)	=J17/D17
18		2	14	1036	=(F17+G17)*H14	=LS*(D18/H14)+(1-LS)*(F17+G17)	=TS*(F18-F17)+(1-TS)*G17	=SS*(D18/F18)+(1-SS)*H14	=D18-E18	=ABS(I18)	=J18/D18
19		3	15	938	=(F18+G18)*H15	=LS*(D19/H15)+(1-LS)*(F18+G18)	=TS*(F19-F18)+(1-TS)*G18	=SS*(D19/F19)+(1-SS)*H15	=D19-E19	=ABS(I19)	=J19/D19
20		4	16	2168	=(F19+G19)*H16	=LS*(D20/H16)+(1-LS)*(F19+G19)	=TS*(F20-F19)+(1-TS)*G19	=SS*(D20/F20)+(1-SS)*H16	=D20-E20	=ABS(I20)	=J20/D20
21	5	1	17		=(F20+G20)*H17					**BIAS**	=AVERAGE(I9:I20)
22		2	18		=(F20+2*G20)*H18					**MAD**	=AVERAGE(J9:J20)
23		3	19		=(F20+3*G20)*H19					**MSE**	=SUMSQ(I9:I20)/11
24		4	20		=(F20+4*G20)*H20					**MAPE**	=AVERAGE(K9:K20)
25											
26											
27											

Notes:
1. Initialization is in cells F5:H8.
2. Type forecasting and updating formulae in cells E9:H9 and then propagate down for the next 11 rows.
3. There are 'different' formulae in cells E22:E24. Reason them out!
4. LS, TS and SS can be changed to better fit sales pattern. Observe effect on error measures and graph.

Simple Linear Regression (SLR): Example

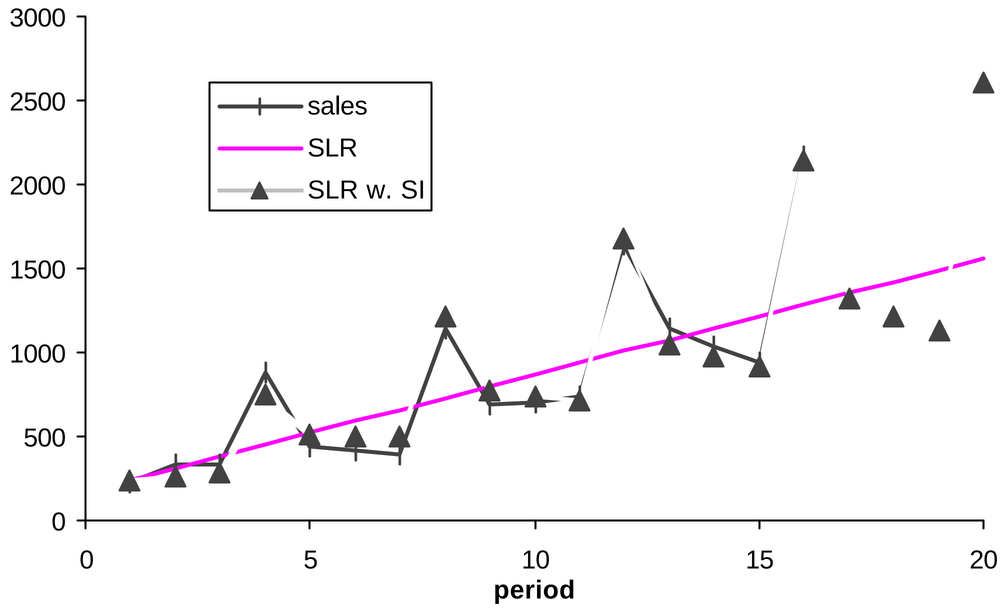
	A	B	C	D	E	F	G	H
1	**Country Greeting Cards: SLR**							
2								
3	**year**	**quarter**	**period**	**sales**	**SLR fc.**		slope =	84.63
4	1	1	1	222	192.3		intercept =	107.68
5		2	2	339	276.9			
6		3	3	336	361.6			
7		4	4	878	446.2			
8	2	1	5	443	530.8			
9		2	6	413	615.5			
10		3	7	398	700.1			
11		4	8	1143	784.7			
12	3	1	9	695	869.4			
13		2	10	698	954.0			
14		3	11	737	1038.6			
15		4	12	1648	1123.3			
16	4	1	13	1141	1207.9			
17		2	14	1036	1292.5			
18		3	15	938	1377.2			
19		4	16	2168	1461.8			
20	5	1	17		1546.5			
21		2	18		1631.1			
22		3	19		1715.7			
23		4	20		1800.4			



Cell:	Formula:	Propagated to:
H3	=SLOPE(D4:D19,C4:C19)	
H4	=INTERCEPT(D4:D19,C4:C19)	
E4	=intercept + slope*C4 (note: ‘intercept’ and ‘slope’ are names that refer to the cells H3 and H4, respectively.)	E5:E19

SLR with Seasonality Indices: Example

	A	B	C	D	E	F	G	H	I
1	**Country Greeting Cards: SLR w SI**							**Seasonality Indices:**	
2								**SI(1)**	**0.97**
3					**slope**	**69.39**		**SI(2)**	**0.85**
4					**intercept**	**173.40**		**SI(3)**	**0.76**
5								**SI(4)**	**1.67**
6	**year**	**quarter**	**period**	**sales**	**SLR**	**SLR w. SI**	**error**	**abs. error**	**% abs. error**
7	1	1	1	222	242.8	**236.3**	-14.3	14.3	6.4%
8		2	2	339	312.2	**266.5**	72.5	72.5	21.4%
9		3	3	336	381.6	**288.9**	47.1	47.1	14.0%
10		4	4	878	451.0	**753.3**	124.7	124.7	14.2%
11	2	1	5	443	520.4	**506.4**	-63.4	63.4	14.3%
12		2	6	413	589.8	**503.4**	-90.4	90.4	21.9%
13		3	7	398	659.1	**499.1**	-101.1	101.1	25.4%
14		4	8	1143	728.5	**1217.0**	-74.0	74.0	6.5%
15	3	1	9	695	797.9	**776.5**	-81.5	81.5	11.7%
16		2	10	698	867.3	**740.3**	-42.3	42.3	6.1%
17		3	11	737	936.7	**709.2**	27.8	27.8	3.8%
18		4	12	1648	1006.1	**1680.6**	-32.6	32.6	2.0%
19	4	1	13	1141	1075.5	**1046.6**	94.4	94.4	8.3%
20		2	14	1036	1144.9	**977.2**	58.8	58.8	5.7%
21		3	15	938	1214.3	**919.4**	18.6	18.6	2.0%
22		4	16	2168	1283.7	**2144.3**	23.7	23.7	1.1%
23	5	1	17		1353.1	**1316.7**			
24		2	18		1422.5	**1214.1**		**BIAS**	-2.0
25		3	19		1491.8	**1129.5**		**MAD**	60.4
26		4	20		1561.2	**2607.9**		**MSE**	**4976.2**
27								**MAPE**	10.3%



How to find the 6 model parameters (slope, intercept, and the 4 seasonality indices):

- The model is as follows:
  SLR w SI forecast =
  (intercept + slope*period)
  *(appropriate seasonality index)
- Set up the SLR w. SI column using this model.
- Plug in reasonable values for the 6 parameters (such as slope = 85, intercept = 108 from regression, and seasonality index = 1 for all quarters).
- Use solver to find the parameter values that minimize MSE. Voila!

Solver settings:

A comparison of TES and SLR w SI

- Both are *additive-trend*, *multiplicative-seasonality* models (the trend is added to the level, and the sum is multiplied by the seasonality index.)
- SLR w SI gives equal weights to past data points, whereas the weights in TES decrease exponentially with the age of the data.
- TES requires less data storage and less computation than SLR w SI approaches. This may be important when forecasting is required for many different products.

One can develop an additive trend and additive seasonality model that is based on regression, or exponential smoothing (a suggested exercise for you).

Numerical comparison (Country Greeting Cards):

Performance Measures			**Forecasts**			**Parameters**		
	TES	**SLR w SI**		**TES**	**SLR w SI**		**TES**	**SLR w SI**
BIAS	60.8	-2.0	**Q1**	1254.7	1316.7	**SI(1)**	0.96	0.97
MAD	132.2	60.4	**Q2**	1200.5	1214.1	**SI(2)**	0.88	0.85
MSE	27,181.4	4,976.2	**Q3**	1133.9	1129.5	**SI(3)**	0.79	0.76
MAPE	17.0%	10.3%	**Q4**	2681.3	2607.9	**SI(4)**	1.78	1.67
						level	1232.3	1283.7
						trend	69.6	69.4

Note: The above figures for TES were found by minimizing MSE subject to LS, TS < 0.3, SS < 0.5. The figures for SLR w SI were found by minimizing MSE. Different solvers may result in slightly different figures, especially for the SLR w SI model.

Steps in a forecasting project

Step -1: Collect data (desirable to have at least two full cycles, otherwise use informal methods.)

Step 0: **Plot the data** (helps to detect trend, seasonality)

Step 1: Decide which models (not) to use

- Level -- SA, SMA, WMA, ES
- Level and trend -- SLR, (TES w. SI forced to equal 1)
- Level, trend and seasonality -- TES, SLR w SI

*(Note: These are the models covered in this course. There are **many** others.)*

Step 2: Use the models chosen in Step 1 (Excel)

Step 3: Compare the models, select one (or more)

Step 4: Generate a forecast and a range (“prediction interval”) to reflect the uncertainty

An alternate seasonality model

The SLR w SI model demonstrated in the lecture notes is an “ad-hoc” model. One can also use the following multiple regression model to account for (quarterly) seasonality:

$$D_t = b_0 + b_1 t + SI(1)X_1 + SI(2)X_2 + SI(3)X_3 + SI(4)X_4 + E_t$$

where:

b_0 = intercept

b_1 = slope (trend)

SI(i) = (additive) seasonality component for quarter i

t = the period

X_i = 1 if period i corresponds to quarter i, 0 otherwise

t, X_i, and D_t are data.

b_0, b_1, and SI(i) can be estimated using Excel’s regression tool, the Xlstat add-in, or specialized statistics software (SYSTAT, MINITAB, SAS, etc.).

Choosing a Forecasting Method

1. **Compare** the performance measures; choose the model with the best measures**.**

2. **Holdback strategy**: If you have data for the last five years, fit the model by using the data for the first four years (holding-back the data for the fifth year). Then “forecast” for the fifth year using the model. Compute the errors generated by the different models for the fifth year, and choose the model with the best performance. After choosing a model, use the data from the fifth year to “calibrate” the model (i.e. repeat the computations using all past data).

3. **If you have several “good” models... choose all!** Research indicates that forecasting performance is almost always improved when forecasts from several different models are combined. The simplest way to combine is to take an average.

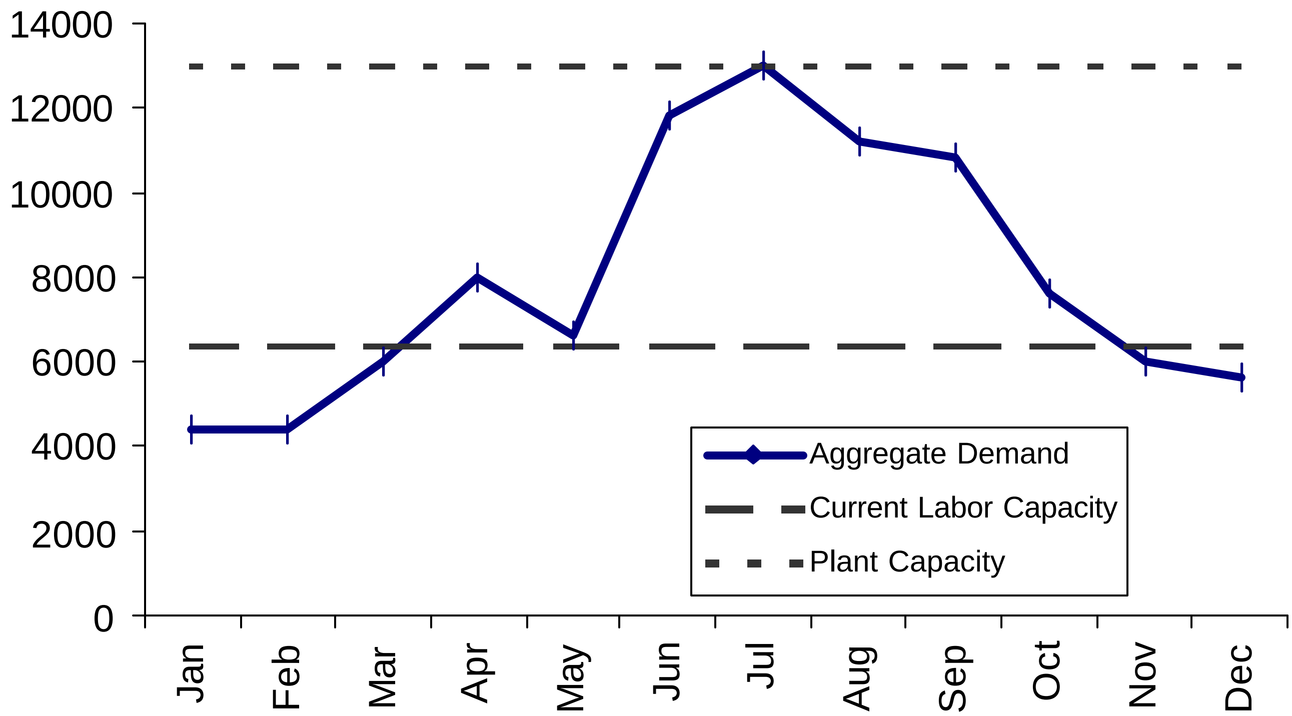
AGGREGATE PLANNING

MacPherson Refrigeration Ltd.

Summary of Data:

- Plant Capacity: units/month
- Labour Productivity: units/worker-year
- # of Workers at Beginning of Year:
- Labour Cost:
- Overtime Labour Cost:
- Hiring Cost:
- Layoff Cost:
- Inventory Holding Cost:
- Inventory on hand at Beginning of Year:

Aggregate demand forecast:



Three ways to track the fluctuating demand:

	Production	Inventory	Workforce	Overtime
Plan 1				
Plan 2				
Plan 3				

Plan 1:

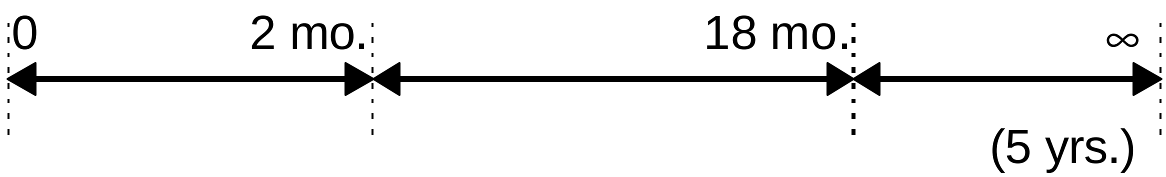
	A	B	C	D	E	F	G
1					**Exhibit 1: Level Production**		
2				*Jan*	*Feb*	*Mar*	*Apr*
3	**Production plan**						
4	*Shipment forecast*			4,400	4,400	6,000	8,000
5	*Production plan*			8,440	8,440	8,440	8,440
6	*Shipments*			4,400	4,400	6,000	8,000
7	*Inventory*			4,280	8,320	10,760	11,200
8							
9	**Extraordinary labour costs**						
10	*No. of workers*			211	211	211	211
11	*Hirings*			51	-	-	-
12	*Layoffs*			-	-	-	-
13	*Worker months overtime*			-	-	-	-
14							
15	**Cost of Alternative 1**						
16	*Hiring costs*			51 x 1800 =	91,800		
17	*Layoff costs*			0 =	0		
18	*Inventory holding costs*			75,000 x 8 =	600,000		
19	*Labour costs*						
20	*Regular*			211 x 12 x 2400 =	6,076,800		
21	*Overtime*				0		
22	*Total*				$6,768,600		

Can we find **a better** plan?

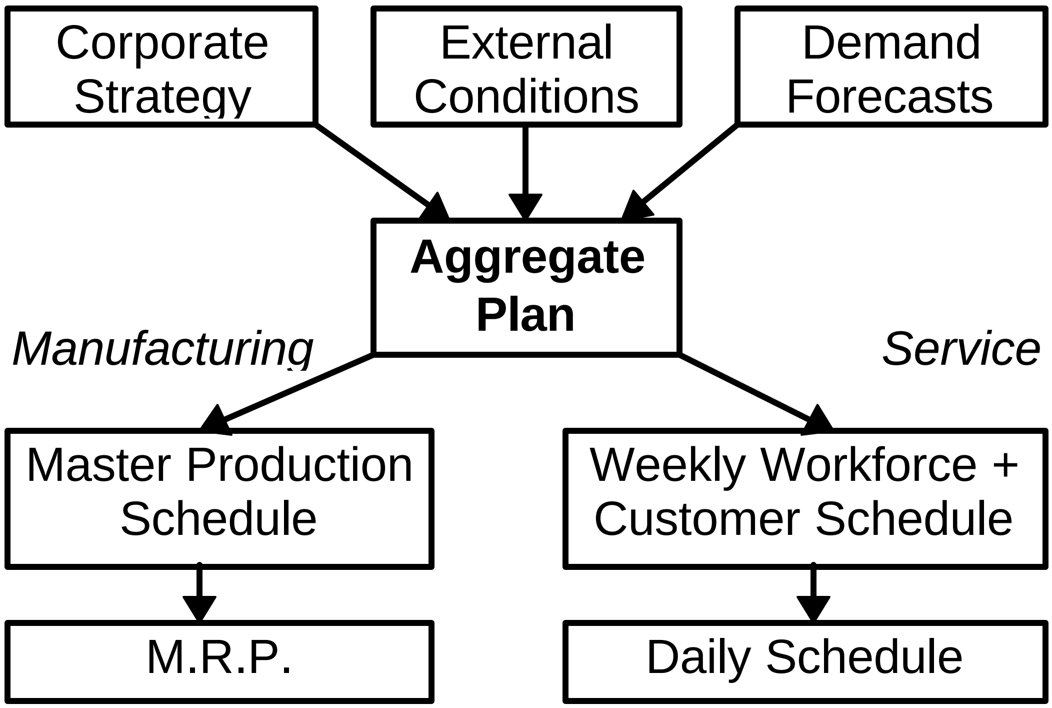
Can we find **the best** plan (lowest cost)?

Overview of Planning

Short-range	Intermediate	Long-range
• Job assignments • Machine loading • Job sequencing • Lot sizing • Order quantities	**Aggregate** levels of: • Workforce • Inventory • Output • Subcontracting • Backorders	• Product or service design • Location • Layout • Capacity • Process



Sequence of Planning



Aggregate Planning

- Intermediate range planning (2 - 18 month time horizon)
- Develops feasible production plan on an aggregate level (products lumped together)
- Relates quantity and timing of expected demand to available capacity
- Inputs: (a) Demand forecasts, (b) Available resources for production, (c) Company policy
- Strategies for matching demand and capacity:
  - ∗ Demand options:

    Pricing
    Promotion
    Back orders
    New demand
  - ∗ Capacity options:

    Hiring/firing
    Overtime/slack time
    Part-time workers
    Subcontracting
    Inventories
- Basic Strategies
  - ∗ Chase:
  - ∗ Level:

Blue Ridge Hot Tubs

Note: This example will be used in the following sections to explain Excel's solver and how to interpret its output.

Blue Ridge Hot Tubs manufactures and sells two models of hot tubs: the Aqua-Spa and the Hydro-Lux. Howie Jones, the owner and manager of the company, is meeting with his staff to decide how many of each type of hot tub to produce during the next production cycle.

Blue Ridge buys prefabricated fiberglass hot tub shells from a local supplier and adds the pump and tubing to the shells to create the hot tubs. Homer Simpson, the production manager, reports that this supplier has the capacity to deliver as many hot tub shells as they need but that Blue Ridge will only be able to obtain 200 pumps during the next production cycle (they install the same type of pump into both hot tubs). From a manufacturing standpoint, the main difference between the two models of hot tubs is the amount of tubing and labour required. Homer reports that each Aqua-Spa requires 9 hours of labour and 12 feet of tubing. Each Hydro-Lux requires 6 hours of labour and 16 feet of tubing. Homer expects to have 1,566 production labour hours and 2880 feet of tubing available during the next production cycle to devote to these two models together.

Andy Marshall, marketing manager, adds that at current prices, they should be able to sell all of the spas that can be produced but that the market is very competitive and that there is no room to raise prices.

Bill Greenspan, Howie's accountant, jumps into the conversation to point out that discussion of the Hydro-Lux is academic because at the current price, it doesn't pay to produce any. He suggests that Homer gear up the plant to only produce Aqua-Spas in this cycle. He produces the following analysis to back up his plan:

	Aqua-Spas	Hydro-Luxes
Selling Price	$2975.00	$2500.00
Variable Costs (incl. labor, tubing)	($2625.00)	($2200.00)
Net Margin	$350.00	$300.00
Less: Allocated Fixed Costs	($310.00)	($310.00)
Profit per unit	$40.00	($10.00)

Bill explains that he allocated the total fixed costs of $62,000 equally among the 200 hot tubs he assumed would be produced – since only 200 pumps are available. He goes on to point out that even the Aqua-Spa has a very low profit, but that the whole picture will change next season when the temporary shortage of pumps is expected to end. This will allow many more hot tubs to be produced, and allow the fixed costs such as heat, light, clerical salaries and property taxes to be spread across many more units than is currently the case.

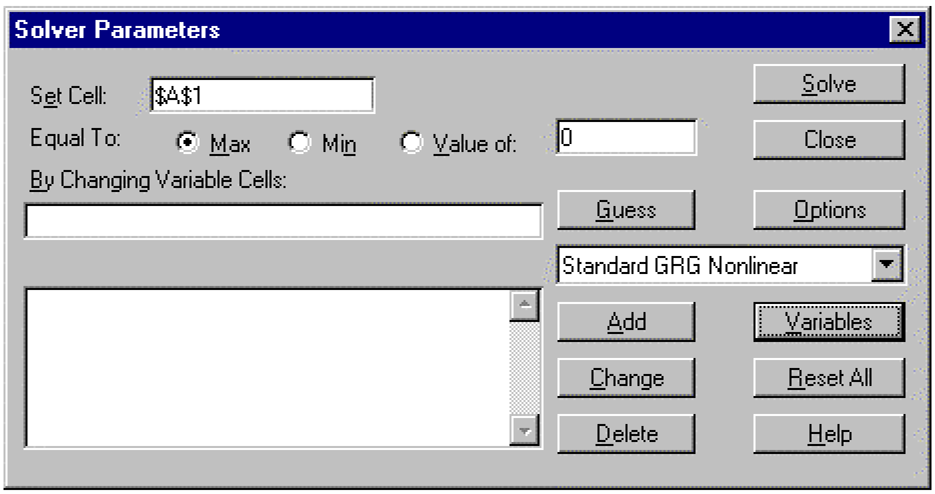
Howie agrees and adds that the whole objective this production cycle is to get through the pump shortage and make as much profit as possible - however small. He then turns to you, Kim Becalm, and asks you to work out a production plan for Homer to follow in the upcoming cycle.

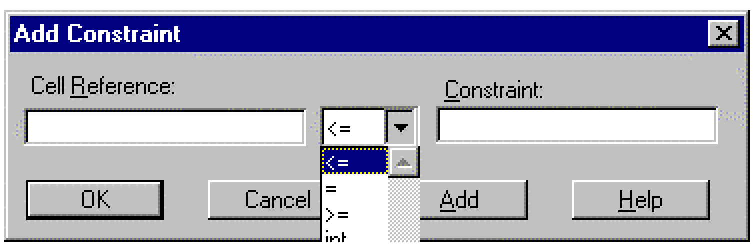
	A	B	C	D	E
1	**Blue Ridge Hot Tubs**				
2					
3		**Aqua-Spas**	**Hydro-Luxes**		
4	**Number to make:**	0	0		**Total Profit:**
5	**Unit Profits:**				$0
6					
7	**Constraints:**			**Used**	**Available**
8	**Pumps Req'd**	1	1	0	200
9	**Labor Req'd**	9	6	0	1566
10	**Tubing Req'd**	12	16	0	2880

Using Solver

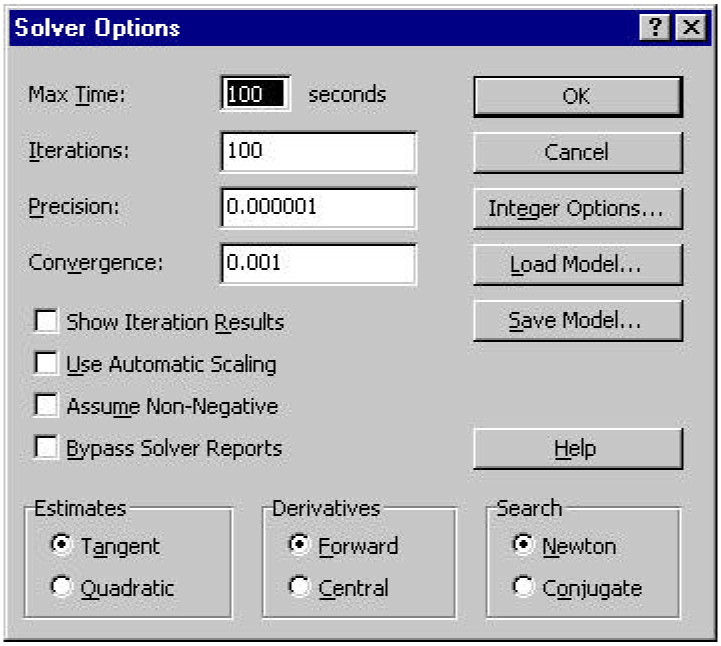
Solver's three main dialog boxes

Note: These dialog boxes are for the Premium Solver, which is available in the Business labs. Dialog boxes for standard Solver are slightly different.

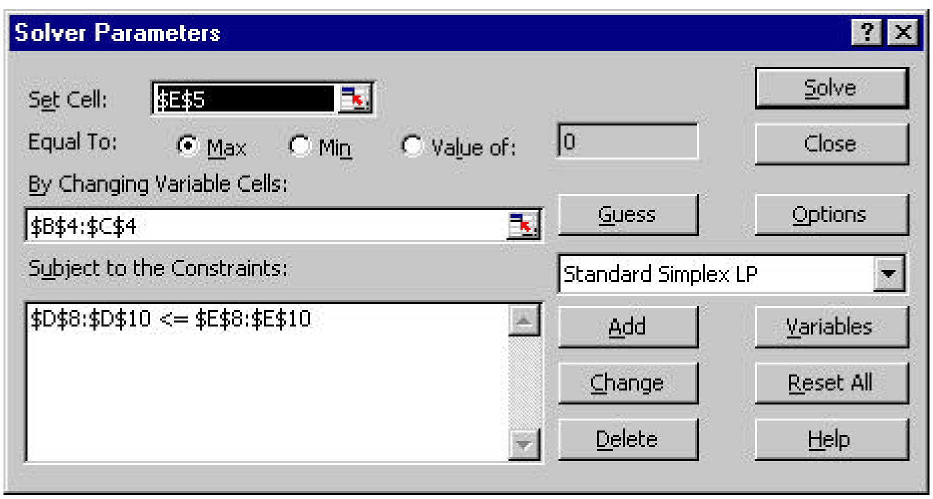


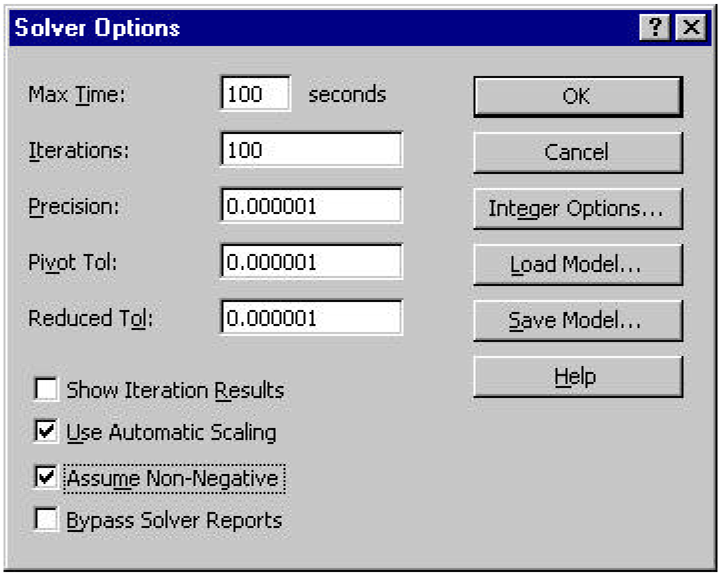


(see next page ...)



Solver Parameters For The Example





Solver Results

If all goes well, Solver fills in the spreadsheet with appropriate values and gives you the option of generating three reports: answer, sensitivity, and limits. We will only use the sensitivity report. The results of the Blue Ridge Hot Tub example are shown here.

	A	B	C	D	E
1	**Blue Ridge Hot Tubs**				
2					
3		**Aqua-Spas**	**Hydro-Luxes**		
4	**Number to make:**	**122**	**78**		**Total Profit:**
5	**Unit Profits:**	$350	$300		$66,100
6					
7	**Constraints:**			**Used**	**Available**
8	**Pumps Req'd**	1	1	200	200
9	**Labor Req'd**	9	6	1566	1566
10	**Tubing Req'd**	12	16	2712	2880

Sensitivity report

Microsoft Excel 8.0e Sensitivity Report
Worksheet: [BLURIDGE.XLS]Sheet1
Report Created: 9/2/99 3:48:52 PM

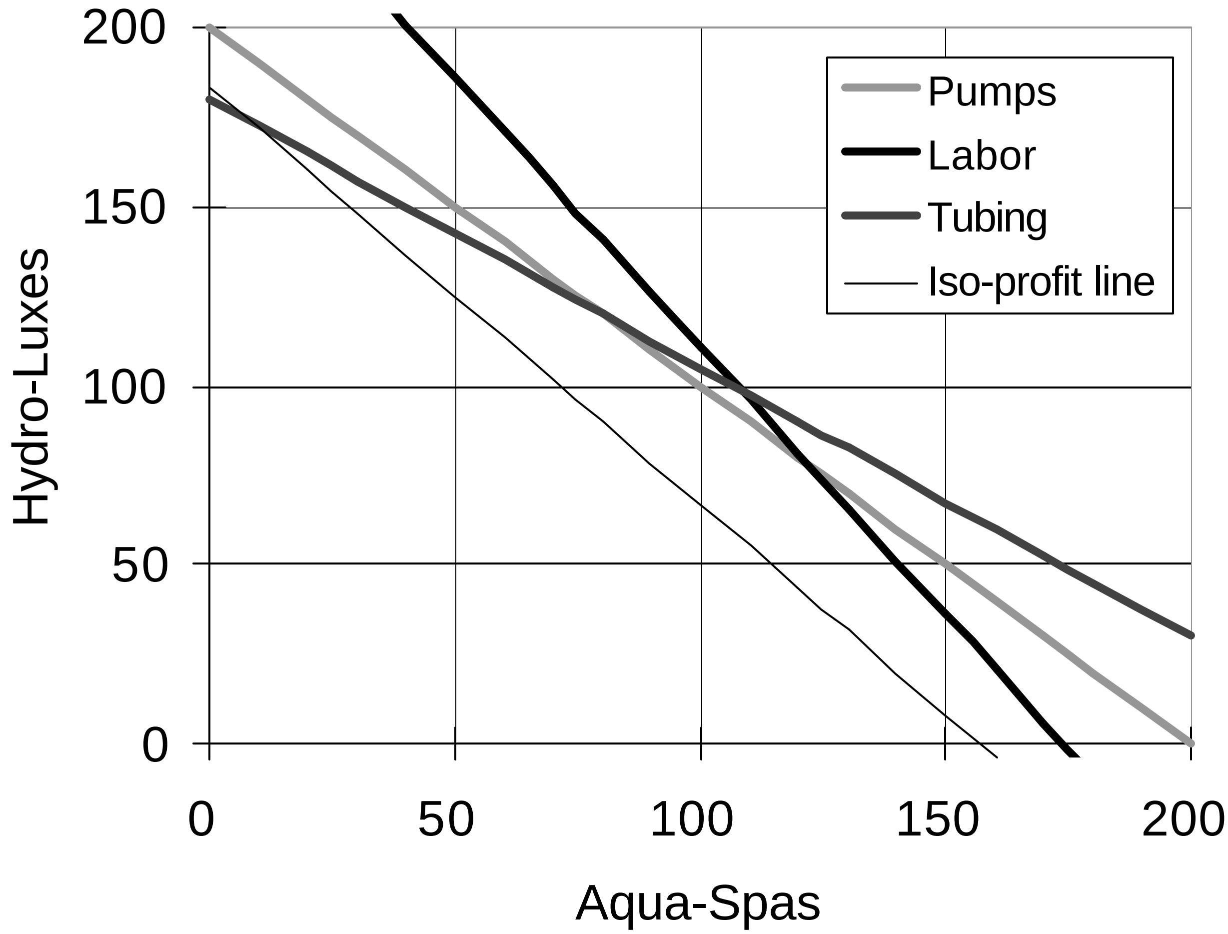
Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$4	Number to make: Aqua-Spas	122	0	350	100	50
$C$4	Number to make: Hydro-Luxes	78	0	300	50	66.66666667

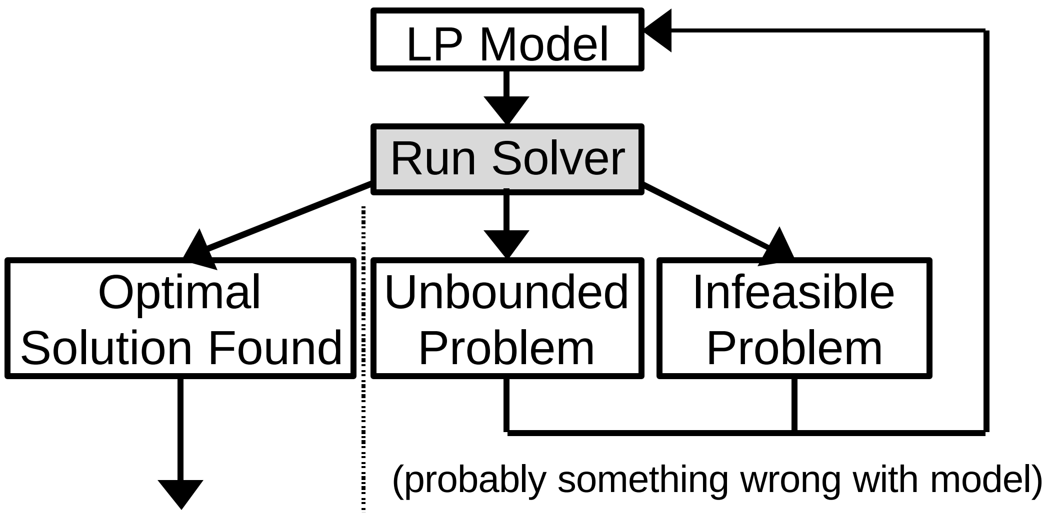
Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$D$8	Pumps Req'd Used	200	200	200	7	26
$D$9	Labor Req'd Used	1566	16.66666667	1566	234	126
$D$10	Tubing Req'd Used	2712	0	2880	1E+30	168

Graphical Interpretation



Possible outcomes of an LP run



Three possibilities:

1. **Unique nondegenerate optimum**

   Sensitivity report is interpreted as explained in the next section.

2. **Multiple optima**

   How to detect?: In the sensitivity report, the allowable increase (or decrease) is zero for one or more objective coefficients.
   Implications: There is at least one more corner solution with the same objective value. There are infinitely many optimal solutions to the problem (between the two corner solutions). However, the information displayed in all reports is valid.

3. **Degenerate optimum**

   How to detect? The number of nonzero decision variables plus the number of nonzero slacks/surpluses (from the answer report) is less than the number of constraints in the model.
   Implications: The solution reported is an optimal solution. However, the information contained in the sensitivity report is not as complete as for the nondegenerate case.

To generate an output with multiple optima, you can solve the Blue Ridge Hot Tubs problem with the objective coefficient of the first product set to $450. To generate an output with a degenerate solution, you can solve the Blue Ridge Hot Tubs problem with 217 pumps available.

Solver's Sensitivity Report

The following applies when the optimal solution is nondegenerate.
We do not summarize the "Answer Report" or the "Limits Report" here.
The answer report provides no information that cannot be obtained from the solution shown on the spreadsheet, and the limits report is not too useful.

Columns in the "Changing Cells" table:

- **Final Value**: Lists the optimal values of the decision variables -- can also be read of the spreadsheet.
- **Reduced Cost** = increase in profit if decision variable were to be increased by one unit (if we are maximizing profit).
  = decrease in cost if decision variable were to be decreased by one unit (if we are minimizing cost).
  Note: A decision variable that is between its simple bounds will always have a reduced cost of zero.
- **Objective Coefficient**: profit that would be achieved if decision variable were set equal to 1, while all other decision variables are set to zero.
- **Allowable Increase/Decrease**: How much the objective coefficient can increase/decrease before the optimal solution to the problem will change. Only valid when changing one coefficient at a time.
- **Remember**: optimal solution = final values of the changing cells.
  optimal objective value = final value of the target cell.

Columns in the "Constraints" table

Interpretation is given for *resource constraints*.

- **Final Value**: Amount of resource consumed in the optimal solution.
- **Shadow Price**: Change in objective value (profit, cost, ...) if one additional unit of the resource becomes available. Note: if the constraint is loose (not all of the resource is consumed) then the shadow price will always be zero.
- **Constraint R.H.Side**: Amount of resource available.
- **Allowable Increase/Decrease**: How much the amount available of the resouce can increase/decrease without the shadow price changing.

Blue Ridge Hot Tub Sensitivity Questions

Microsoft Excel 8.0e Sensitivity Report
Worksheet: [BLURIDGE.XLS]Sheet1
Report Created: 9/2/99 3:48:52 PM

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$4	Number to make: Aqua-Spas	122	0	350	100	50
$C$4	Number to make: Hydro-Luxes	78	0	300	50	66.66666667

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$D$8	Pumps Req'd Used	200	200	200	7	26
$D$9	Labor Req'd Used	1566	16.66666667	1566	234	126
$D$10	Tubing Req'd Used	2712	0	2880	1E+30	168

1. Howie realizes that he underestimated the profit for Aqua Spas by $65. Is the solution still valid? If not, how will it change?

2. Howie realizes that he overestimated the profit for Aqua Spas by $65. Is the solution still valid? If not, how will it change?

3. Howie discovers a new market where he can sell each one of his products for 20% more profit than he originally estimated. Is the solution still valid? If not, how will it change?

4. An independent contractor offers Howie 5 more pumps for a **premium** of $150 each **(above and beyond the going rate** of $720 per pump**)**. Should Howie buy these pumps?

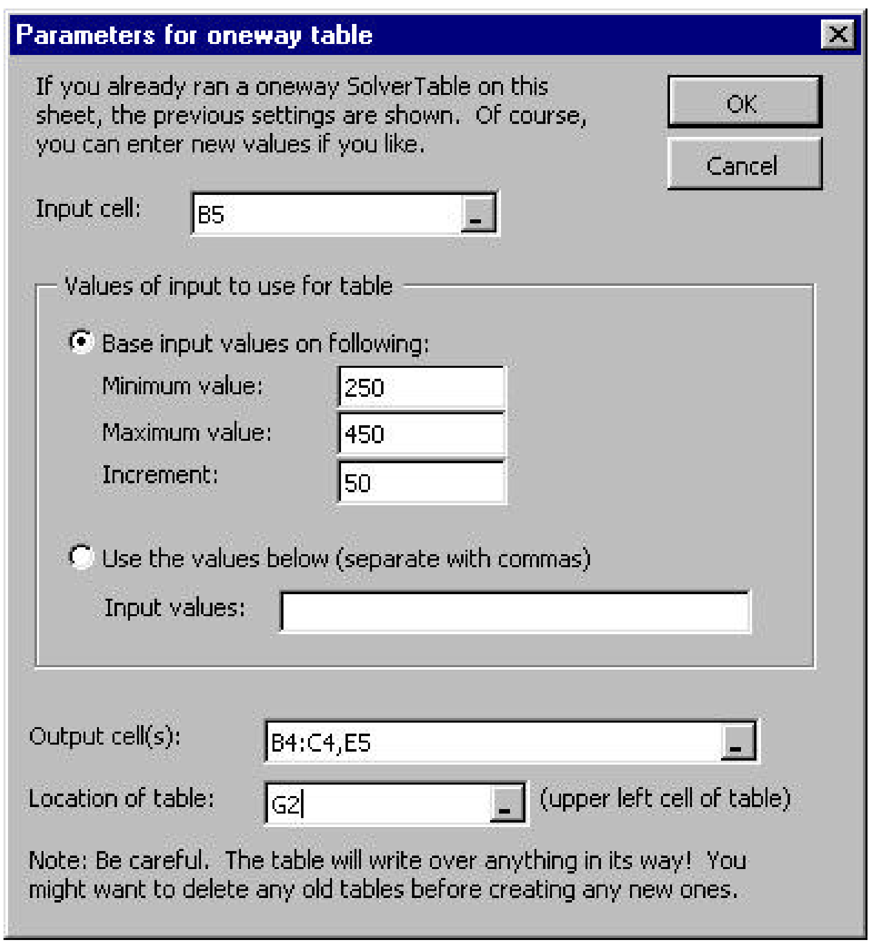
5. His nephew offers to work for Howie for a **premium** of $12 per hour (**above and beyond the going rate** of $20 per hour). Should Howie hire his nephew? For how many hours?

Solver Table

The SolverTable add-in provides an alternative way to do sensitivity analysis. You will be given instructions on how to install it.

We will use the SolverTable to answer questions 1 and 2 from the last section.

Open the Bluridge.xls workbook. Choose Data ➔ Solver Table … . Choose "one way table," click "OK" and fill in the dialog box as follows:



After adding some labels and doing some formatting, the table should look as follows:

	G	H	I	J
1	**A-S Unit**	**A-S to make**	**H-L to make**	**Tot. Profit**
2	**Profit**	$B$4	$C$4	$E$5
3	250	80	120	$56,000
4	300	122	78	$60,000
5	350	122	78	$66,100
6	400	122	78	$72,200
7	450	174	0	$78,300

The SolverTable add-in generated the table by running Solver repeatedly, once for each value of the Aqua Spa unit profit we asked it to try. From the table we can see that:

LP software

Excel's Solver

You have seen how Excel's **Solver** is used for linear programming (LP). Its **advantages**:

- it comes with Excel (at no additional cost).
- it has the same familiar user interface as other Excel components.
- it can solve problems with integer constraints and nonlinear problems, as well as LP's.
- its use can be automated using Visual Basic for Applications (VBA).

However, the **disadvantages** are:

- regular Solver is limited to 200 variables and 100 constraints. Premium Solver can handle 800 variables (for linear problems), and has no limit on the number of constraints.
- it is somewhat inconvenient. Example: no arithmetic is allowed on the left-hand-side when entering the constraints (B12 + B13 $\leq$ B14 is not allowed).
- it can be slow, especially when solving large problems with integer constraints. Premium Solver is much faster.
- it is not very reliable. Sometimes it fails to find an optimal – or even feasible – solution when an optimal solution is known to exist.

The standard Excel Solver may not be suitable for large or complicated real problems. However, according to FrontLine Systems (the company that makes Solver),

- # of problems with less than 200 variables = (5-10)*(# of larger problems)
- A Fortune 50 company was able to solve $7 M/year with a Solver problem with less than 200 variables.

These small problems are the ones you can solve, and there are lots of them. For larger and more complex problems, you may need a master's or PhD in Management Science.

It is possible to purchase much-improved versions of the solver (such as Premium Solver) separately.

Information on other software packages

- A 1999 survey in *OR/MS Today* lists 41 products.
- Prices range from $25 to $8,000.
- An inexpensive package can solve problems with 2,500 constraints, 12,500 variables, and 64,000 non-zero coefficients. High end products can solve problems of any size (limited only by the memory and speed of the computer).
- Many products are available on a variety of platforms (Windows, Macintosh, Unix)
- Most packages include Integer Programming, some include Nonlinear Programming.

MacPherson Refrigeration

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		**Jan**	**Feb**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Totals**
2	**Prod'n Plan**													
3	Shipm. forec.													
4	Prod'n plan													
5	Shipments													
6	Inventory													
7														
8	**Workforce:**													
9	No. of workers													
10	Hirings													
11	Layoffs													
12	Overtime													
13	Labor capacity													
14	Phys. capacity													
15														
16	**Cost**													
17	Hiring costs													
18	Layoff costs													
19	Inv. holding													
20	**Labour costs**													
21	Regular													
22	Overtime													
23	**Total Cost**													

Completed Spreadsheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Totals**
2	**Production Plan**													
3	Shipment forecast	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
4	Production plan	**6400**	**6400**	**6400**	**6400**	**9453.3**	**9453.3**	**9453.3**	**11200**	**10800**	**7600**	**6000**	**5600**	95160
5	Shipments	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
6	Inventory	2240	4240	4640	3040	5893.3	3546.7	5E-12	0	0	0	0	0	23600
7														
8	**Workforce:**													
9	No. of workers	160	160	160	160	236.33	236.33	236.33	236.33	236.33	190	150	140	2302
10	Hirings	**0**	**0**	**0**	**0**	**76.333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	76
11	Layoffs	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**46.333**	**40**	**10**	96
12	Worker months overtime	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**43.667**	**33.667**	**0**	**0**	**0**	77
13	Labor capacity	6400	6400	6400	6400	9453.3	9453.3	9453.3	11200	10800	7600	6000	5600	95160
14	Physical Capacity	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	
15														
16	**Cost**													
17	Hiring costs		$ 137,400											
18	Layoff costs		$ 115,600											
19	Inventory holding costs		$ 188,800											
20	**Labour costs**													
21	Regular		$ 5,524,000											
22	Overtime		$ 255,200											
23	**Total Cost**		$ 6,221,000											
24														

Solver Settings:

Set Cell: C23

Equal to: MIN

By changing cells: B4:M4, B10:M12

Subject to: B4:M4 >= 0

B10:M12 >= 0

B4:M4 <= B13:M13

B4:M4 <= B14:M14

B6:M6 >= 0

Formula View

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Totals**
2	**Production**													
3	Shipment for	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	=SUM(B3:M3)
4	Production p	6400	6400	6400	6400	9453.3	9453.3	9453.3	11200	10800	7600	6000	5600	=SUM(B4:M4)
5	Shipments	=B3	=C3	=D3	=E3	=F3	=G3	=H3	=I3	=J3	=K3	=L3	=M3	=SUM(B5:M5)
6	Inventory	=240+B4-B5	=B6+C4-C5	=C6+D4-D5	=D6+	=E6+	=F6+	=G6+	=H6+	=I6+J	=J6+K	=K6+L	=L6+M4-M5	=SUM(B6:M6)
7														
8	**Workforce:**													
9	No. of worke	=160+B10-B11	=B9+C10-C11	=C9+D10-D11	=D9+	=E9+	=F9+	=G9+	=H9+	=I9+J	=J9+K	=K9+L	=L9+M10-M11	=SUM(B9:M9)
10	Hirings	0	0	0	0	76.33	0	0	0	0	0	0	0	=SUM(B10:M10)
11	Layoffs	0	0	0	0	0	0	0	0	0	46.33	40	10	=SUM(B11:M11)
12	Worker mon	0	0	0	0	0	0	0	43.66	33.66	0	0	0	=SUM(B12:M12)
13	Labor capac	=40*(B9+B12)	=40*(C9+C12)	=40*(D9+D12)	=40*(	=40*(	=40*(	=40*(	=40*(	=40*(	=40*(	=40*(	=40*(M9+M12)	=SUM(B13:M13)
14	Physical Cap	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	
15														
16	**Cost**													
17	Hiring costs		=N10*1800											
18	Layoff costs		=N11*1200											
19	Inventory hol		=N6*8											
20	**Labour cost**													
21	Regular		=N9*2400											
22	Overtime		=N12*3300											
23	**Total Cost**		=SUM(C17:C22)											
24														

Solver Settings:
Set Cell: C23
Equal to: MIN
By changing cells: B4:M4, B10:M12
Subject to: B4:M4 >= 0
B10:M12 >= 0
B4:M4 <= B13:M13
B4:M4 <= B14:M14
B6:M6 >= 0

Air Alberta

Air Alberta is doing aggregate planning of their flight attendant staffing for the next 6 months. They have made a forecast of the number of flight attendant hours needed in each of the upcoming months based on scheduled flights and wish to determine how many attendants need to be hired each month. Each trained attendant on staff can supply 150 hours of flying time per month. The first month that an attendant is hired they are called trainees and their net contribution to flying time is negative (-100 hours) because they require supervision which detracts from the productivity of other attendants. Each trained attendant costs $1500 in salary and benefits per month while each trainee costs $700 per month. Normal attrition (resignations and dismissals) in this occupation is high, 10% per month, so Air Alberta never has any planned layoffs. Trainees are hired on the first day of each month and become attendants on the first of the next month (with no attrition). As of March 1, Air Alberta has 60 trained attendants.

	A	B	C	D	E	F	G
1	**Air Alberta**	**Flight Attendant Staffing Plan**					
2							
3		March	April	May	June	July	August
4	Attendant Hrs. needed	8000	7000	8000	10000	9000	12000
5	Trained Attendants	60	54	48.6	43.74	39.366	35.4294
6	Trainees Hired	0	0	0	0	0	0
7	Attendant Hrs. Available	9000	8100	7290	6561	5904.9	5314.41
8	Monthly Staffing Cost	$ 90,000	$ 81,000	$ 72,900	$ 65,610	$ 59,049	$ 53,144
9							
10	Turnover rate:	10%	/month		**Total Staffing Cost:**		$ 421,703.10
11	Attendant cost	$1,500	/person/month				
12	Trainee cost:	$700	/person/month				
13	Attendant availability:	150	/person/month				
14	Trainee availability:	-100	/person/month				

1. Solver settings to find a least cost staffing plan:

2. The least cost staffing plan:
   hire ___ in March, ___ in April, ___ in May, ___ in June, ___ in July, and ___ in August.

3. The total cost of this plan is $____________

4. In which months does Air Alberta have excess attendant hours available? ________________

5. Air Alberta is considering running extra charter flights requiring 1000 flight attendant hours in either June or July. Which month would you choose so as to minimize the costs of hiring extra flight attendants? ____________________

   Why? ____________________________
   ____
   ____

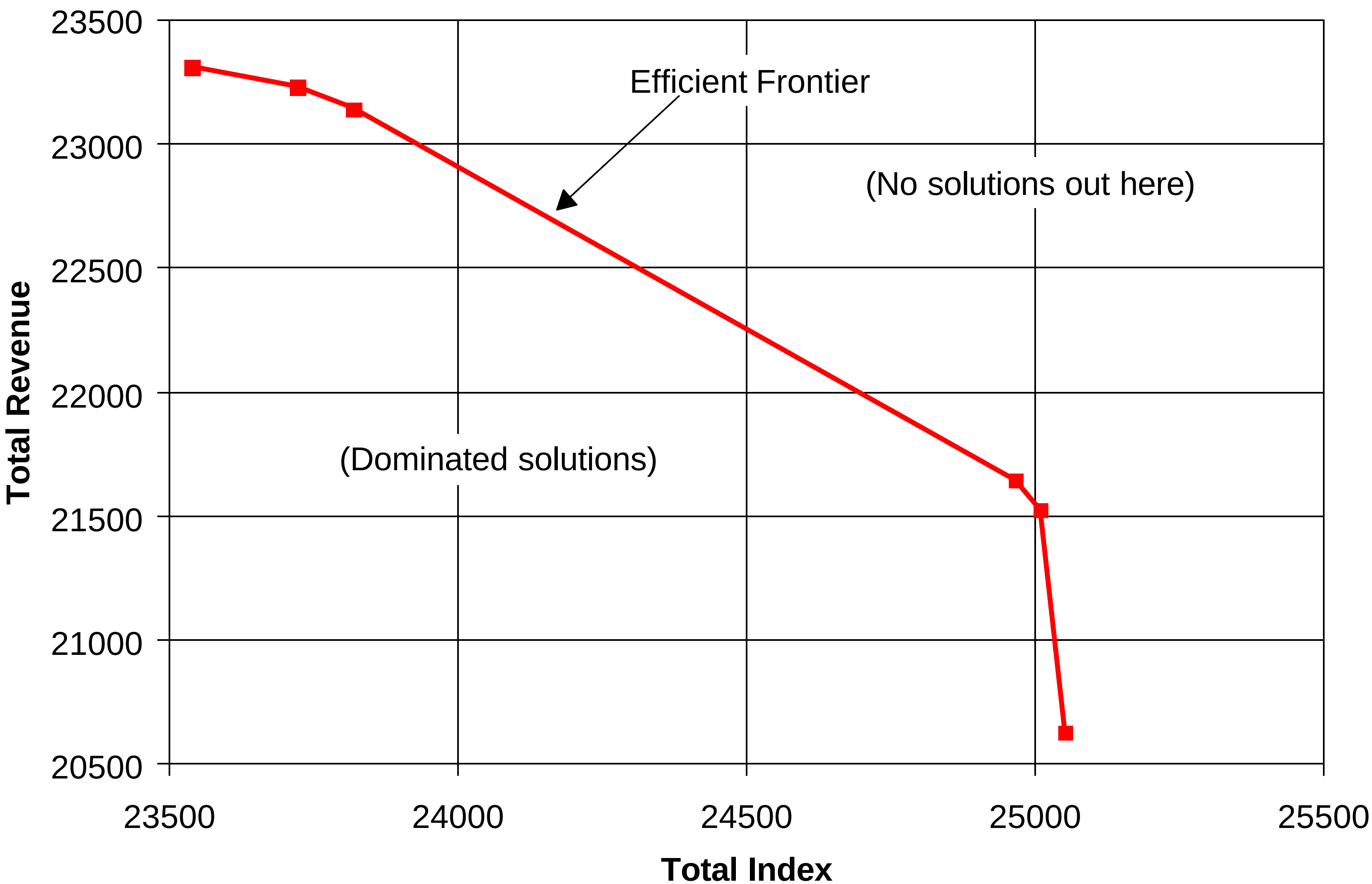
WestPlast Ltd.

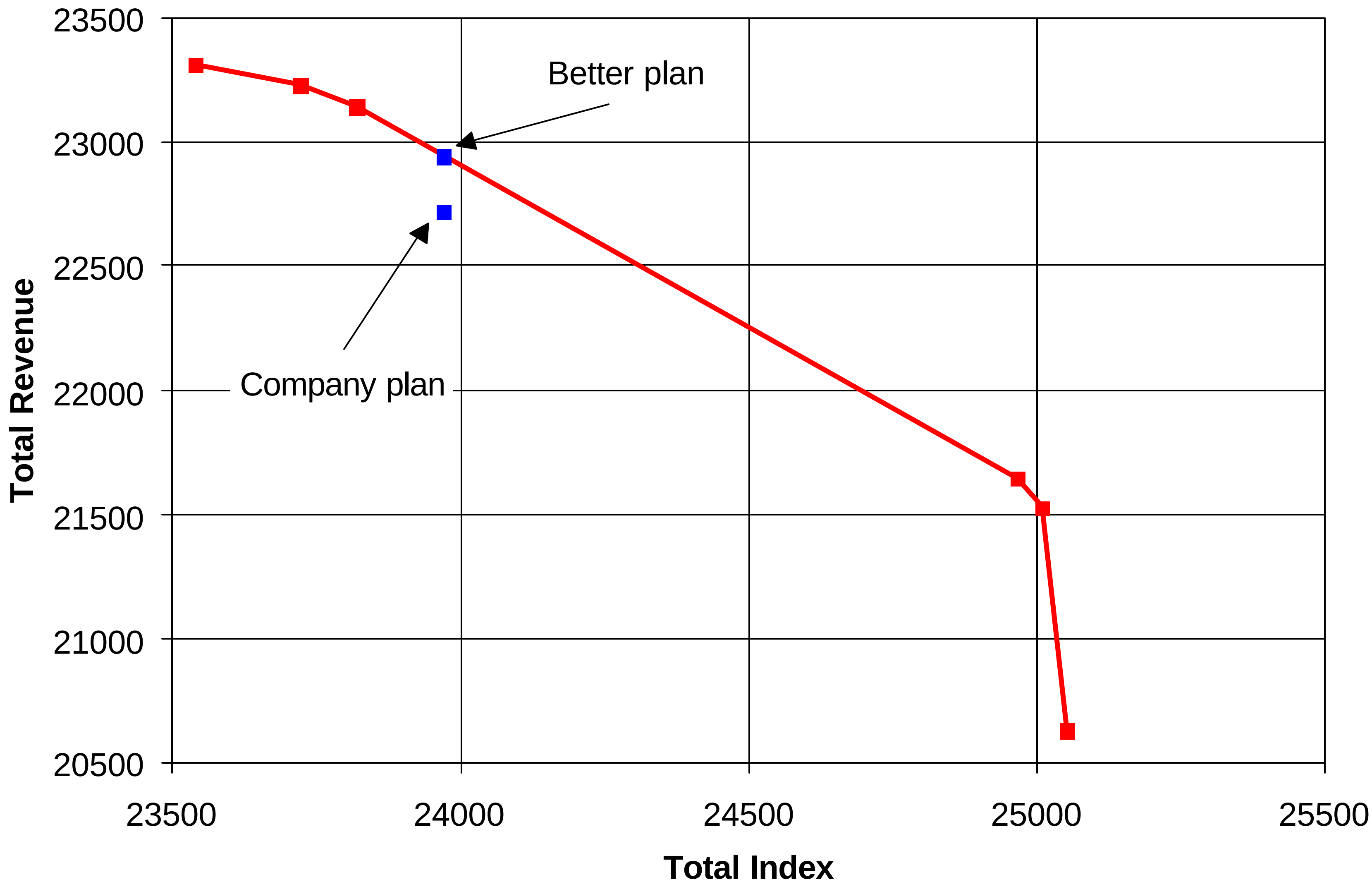
	A	B	C	D	E	F	G	H
1	**WestPlast Product Mix**							
2	**Pellet**	**Market**	**Index**	**Revenue**	**Demand**	**Contracts**		
3	E	Canada	63	100.0	30	0		
4	B	Altoil	58	81.1	16	16		
5	C	Canada	65	69.8	30	0		
6	A1	Colpop	78	67.3	135	135		
7	C	Export	62	65.8	70	0		
8	A2	Canada	78	61.6	30	30		
9	F2	Calcan	65	57.7	10	10		
10	D	Local	65	57.4	35	0		
11	A2	Export	78	51.6	20	0		
12	F1	Canada	85	35.8	50	0		
13								
14								
15								

	A	B	C	D	E	F	G	H
1	**WestPlast Product Mix**							**Better**
2	**Pellet**	**Market**	**Index**	**Revenue**	**Demand**	**Contracts**	**Plan**	**Plan?**
3	E	Canada	63	100.0	30	0	**30**	**30**
4	B	Altoil	58	81.1	16	16	**16**	**16**
5	C	Canada	65	69.8	30	0	**30**	**30**
6	A1	Colpop	78	67.3	135	135	**135**	**135**
7	C	Export	62	65.8	70	0	**30**	**57.3913**
8	A2	Canada	78	61.6	30	30	**30**	**30**
9	F2	Calcan	65	57.7	10	10	**10**	**10**
10	D	Local	65	57.4	35	0	**35**	**0**
11	A2	Export	78	51.6	20	0	**10**	**20**
12	F1	Canada	85	35.8	50	0	**9**	**6.6087**
13						**Total Index:**	23968	23968
14	**Total amount:**		335		**Total Revenue:**		22723.3	22947
15	**Capacity:**		335					

	A	B	C	D	E	F	G	H
1	**WestPlast Product Mix**							
2	**Pellet**	**Market**	**Index**	**Revenue**	**Demand**	**Contracts**	**Amount**	
3	E	Canada	63	100.0	30	0	**9**	
4	B	Altoil	58	81.1	16	16	**16**	
5	C	Canada	65	69.8	30	0	**30**	
6	A1	Colpop	78	67.3	135	135	**135**	
7	C	Export	62	65.8	70	0	**0**	
8	A2	Canada	78	61.6	30	30	**30**	
9	F2	Calcan	65	57.7	10	10	**10**	
10	D	Local	65	57.4	35	0	**35**	
11	A2	Export	78	51.6	20	0	**20**	
12	F1	Canada	85	35.8	50	0	**50**	**Weights:**
13						**Total Index:**	25050	**1.00**
14	**Total amount:**		335			**Total Revenue:**	20633.1	**0.00**
15	**Capacity:**		335					
16						**Weighted objective:**	25050	

	A	B	C	D	E	F	G	H
1	**Generating the Efficient Frontier**							
2	**Pellet**	**Market**	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
3	E	Canada	**9**	**30**	**30**	**30**	**30**	**30**
4	B	Altoil	**16**	**16**	**16**	**16**	**16**	**16**
5	C	Canada	**30**	**30**	**30**	**30**	**30**	**30**
6	A1	Colpop	**135**	**135**	**135**	**135**	**135**	**135**
7	C	Export	**0**	**0**	**14**	**64**	**70**	**70**
8	A2	Canada	**30**	**30**	**30**	**30**	**30**	**30**
9	F2	Calcan	**10**	**10**	**10**	**10**	**10**	**10**
10	D	Local	**35**	**14**	**0**	**0**	**0**	**14**
11	A2	Export	**20**	**20**	**20**	**20**	**14**	**0**
12	F1	Canada	**50**	**50**	**50**	**0**	**0**	**0**
13		**Total Index:**	25050	25008	24966	23816	23720	23538
14		**Total Revenue:**	20633.1	21527.7	21645.3	23145.3	23230.5	23311.7
15		**Index weight:**	**1.0**	**0.8**	**0.6**	**0.5**	**0.4**	**0.0**


Efficient Frontier
(No solutions out here)
(Dominated solutions)
Total Revenue
Total Index
23500
23000
22500
22000
21500
21000
20500
23500
24000
24500
25000
25500



Total Revenue
23500
23000
22500
22000
21500
21000
20500
23500
24000
24500
25000
25500
Total Index
Better plan
Company plan

Yes/No Decisions

Sometimes we need to make "yes/no" or "on/off" type decisions, for example:

- Produce a positive number of widgets, or produce no widgets.
- Include salad in daily diet, or not.
- Build new plant, or not.

Solver can be made to make these types of decisions, by defining a **yes/no decision variable**. Suppose we want cell A1 to contain the number "1" if any widgets are produced at all, and "0" if no widgets are produced. Solver must be told that the only numbers allowed in cell A1 are 0 and 1. We do this by entering a constraint that A1 has to be **binary**.

(Older versions of solver don't have the binary option. Instead, one has to enter the three constraints: A1 $\geq$ 0, A1 $\leq$ 1, A1 integer.)

Linking Yes/No Variables with Other Variables

Making widgets involves an expensive set-up procedure, so suppose we have a policy that if any widgets are made at all, at least 10 widgets must be made. Also, no more than 100 widgets can be made during one production run, because the machine is needed to produce other products also. How can we make sure these policy decisions are enforced?

Let cell A2 contain the number of widgets produced -- another decision variable. We need to make sure that

- If A1 = 0, then A2 must be 0.
- If A1 = 1, then A2 can be between 10 and 100.

The following constraints will make sure this happens:

- $A2 \geq 10*A1$
- $A2 \leq 100*A1$

Potential Pitfall

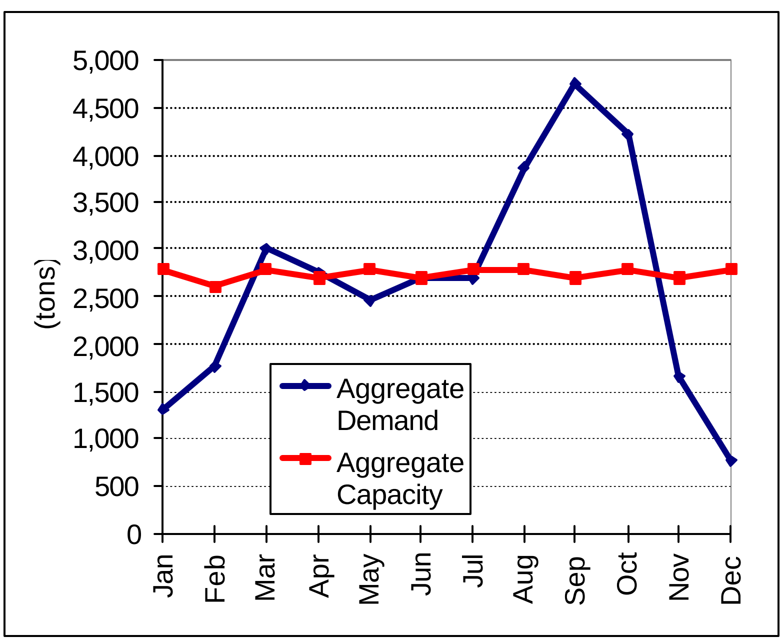
It is very tempting to use Excel's IF() function to define yes/no variables. For example, in the above example, it is tempting to type the formula =IF(A2>0, 1, 0) in cell A1. The short answer to whether this is a good idea is

> **No**!!! Do **not** use IF() functions to define Yes/No decision variables! ☠

The reason is that IF() functions cause the constraints, or the objective function, or both, to become nonlinear and discontinuous functions of the decisions variables. This makes the problem much more difficult to solve. Result: Solver may not find a solution, and if it does find a solution, it may not be the best solution.

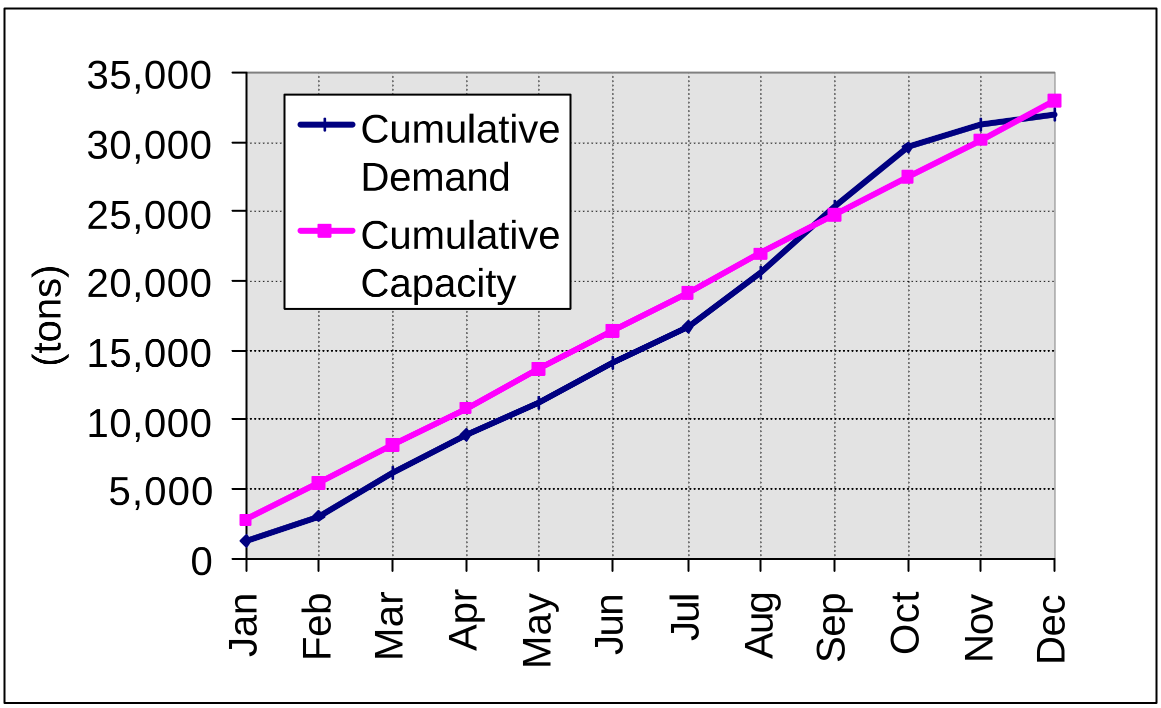
AltaMetal Ltd.

AltaMetal Ltd. Estimated Monthly Demand (tons)												
Prod. group	JAN	FEB.	MAR	APR	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC
A	281	341	614	786	1,028	680	418	388	397	549	378	109
B	13	17	9	52	63	8	12	191	134	71	21	21
C	28	38	26	40	16	102	434	610	898	470	32	42
D	75	204	240	242	102	482	514	929	610	544	201	168
E	35	90	63	91	11	104	229	290	252	233	70	63
F	501	736	1,508	1,099	831	575	476	741	948	771	439	216
G	350	292	487	348	358	574	400	262	294	549	431	85
H	14	40	45	73	43	65	52	104	78	294	40	35
I	9	13	18	22	12	102	170	353	1,135	734	39	28
Totals:	1,307	1,770	3,010	2,753	2,462	2,694	2,704	3,867	4,747	4,215	1,651	767
Total annual demand:				31,949	tons/year							
Daily capacity:		90	tons/day									
Monthly Capacity (tons)												
	JAN	FEB.	MAR	APR	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC
days	31	29	31	30	31	30	31	31	30	31	30	31
capacity	2,790	2,610	2,790	2,700	2,790	2,700	2,790	2,790	2,700	2,790	2,700	2,790
Annual capacity:				32,940	tons/year							
Capacity utilization:				97%								



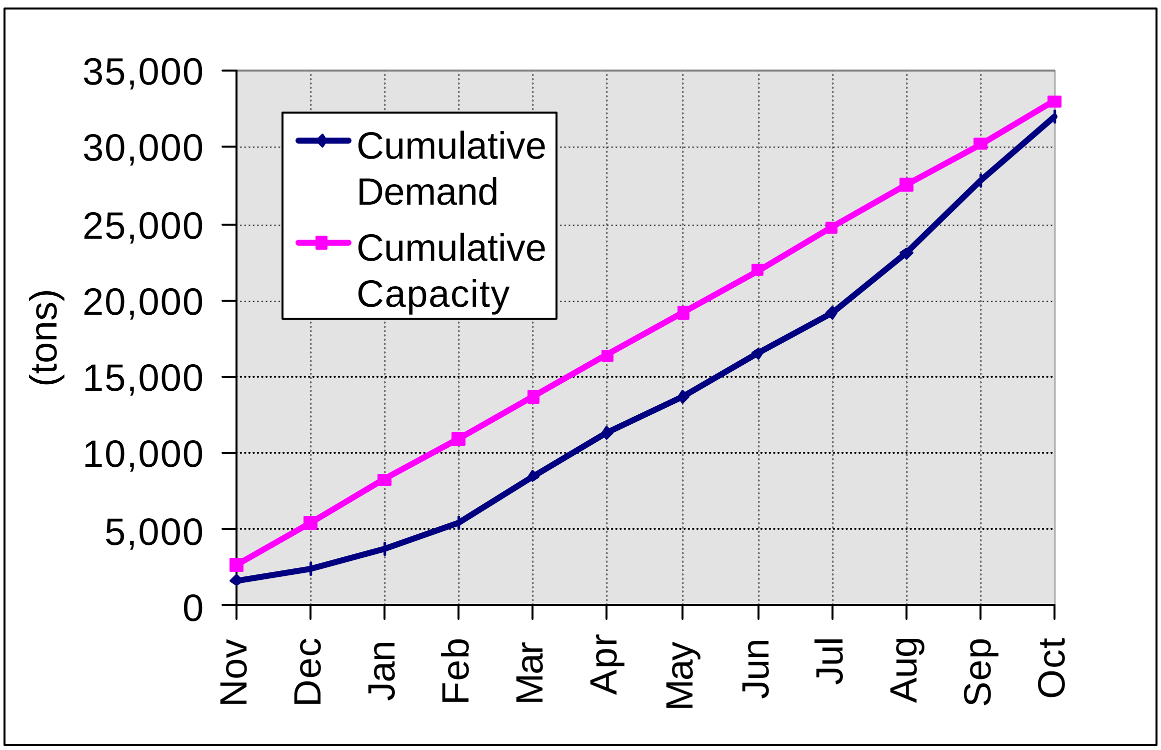
Aggregate Plan 1

	A	B	C	D	E	F	G
1			Cumulative		Cumulative		Demand
2		Demand	Demand	Capacity	Capacity	Surplus	satisfied?
3	Jan	1,307	1,307	2,790	2,790	1,483	Yes
4	Feb	1,770	3,077	2,610	5,400	2,323	Yes
5	Mar	3,010	6,087	2,790	8,190	2,103	Yes
6	Apr	2,753	8,840	2,700	10,890	2,050	Yes
7	May	2,462	11,303	2,790	13,680	2,377	Yes
8	Jun	2,694	13,996	2,700	16,380	2,384	Yes
9	Jul	2,704	16,701	2,790	19,170	2,469	Yes
10	Aug	3,867	20,568	2,790	21,960	1,392	Yes
11	Sep	4,747	25,315	2,700	24,660	-655	No
12	Oct	4,215	29,530	2,790	27,450	-2,080	No
13	Nov	1,651	31,182	2,700	30,150	-1,032	No
14	Dec	767	31,949	2,790	32,940	991	Yes



Aggregate Plan 2

	A	B	C	D	E	F	G
1			Cumulative		Cumulative		Demand
2		Demand	Demand	Capacity	Capacity	Surplus	satisfied?
3	Nov	1,651	1,651	2,700	2,700	1,049	Yes
4	Dec	767	2,419	2,790	5,490	3,071	Yes
5	Jan	1,307	3,726	2,790	8,280	4,554	Yes
6	Feb	1,770	5,495	2,610	10,890	5,395	Yes
7	Mar	3,010	8,506	2,790	13,680	5,174	Yes
8	Apr	2,753	11,259	2,700	16,380	5,121	Yes
9	May	2,462	13,721	2,790	19,170	5,449	Yes
10	Jun	2,694	16,415	2,700	21,870	5,455	Yes
11	Jul	2,704	19,119	2,790	24,660	5,541	Yes
12	Aug	3,867	22,986	2,790	27,450	4,464	Yes
13	Sep	4,747	27,733	2,700	30,150	2,417	Yes
14	Oct	4,215	31,949	2,790	32,940	991	Yes



JIT Production Plan

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**AltaMetal Ltd. Estimated Monthly Demand (tons)**												
2	**Prod.**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
3	**A**	378.0	108.7	281.4	340.5	614.0	785.6	1,027.7	680.2	417.9	387.9	397.5	549.2
4	**B**	21.4	20.9	13.0	17.2	9.3	52.2	62.5	7.9	11.8	191.0	133.8	70.8
5	**C**	31.8	42.5	28.1	37.8	26.0	40.0	15.8	102.4	434.4	610.4	898.3	469.8
6	**D**	201.3	168.3	75.4	203.8	239.9	242.2	101.8	482.3	514.3	928.6	609.8	544.4
7	**E**	69.6	63.3	35.3	89.8	62.7	90.5	11.4	104.3	228.7	289.8	252.3	233.2
8	**F**	438.6	215.6	501.1	735.9	1,507.7	1,099.3	831.0	575.2	476.0	740.5	948.1	770.6
9	**G**	431.4	85.2	349.9	291.9	487.1	347.6	357.6	573.8	399.8	261.8	294.0	548.7
10	**H**	39.8	34.8	14.0	40.0	45.4	73.2	43.0	65.3	51.6	104.0	77.9	294.5
11	**I**	39.2	28.0	9.2	12.8	18.2	22.5	11.6	102.3	169.6	353.2	1,135.3	734.3
12													
13	Daily capacity:		90	tons/day									
14													
15	**Production (tons)**												
16	**Prod.**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
17	**A**	**378.0**	**543.5**	**0.0**	**187.1**	**614.0**	**785.6**	**1,027.7**	**680.2**	**417.9**	**387.9**	**397.5**	**549.2**
18	**B**	**21.4**	**33.8**	**0.0**	**26.5**	**0.0**	**52.2**	**62.5**	**7.9**	**11.8**	**191.0**	**133.8**	**70.8**
19	**C**	**31.8**	**70.6**	**0.0**	**63.8**	**0.0**	**40.0**	**15.8**	**102.4**	**434.4**	**610.4**	**898.3**	**469.8**
20	**D**	**201.3**	**447.5**	**0.0**	**0.0**	**239.9**	**242.2**	**101.8**	**482.3**	**514.3**	**928.6**	**609.8**	**544.4**
21	**E**	**69.6**	**98.6**	**0.0**	**152.4**	**0.0**	**90.5**	**11.4**	**104.3**	**228.7**	**289.8**	**252.3**	**233.2**
22	**F**	**438.6**	**1,452.6**	**0.0**	**0.0**	**1,507.7**	**1,099.3**	**831.0**	**766.4**	**1,182.8**	**382.3**	**408.3**	**770.6**
23	**G**	**516.2**	**143.3**	**207.0**	**1,295.3**	**428.4**	**390.2**	**739.8**	**556.4**	**0.0**	**0.0**	**0.0**	**152.0**
24	**H**	**74.6**	**0.0**	**14.0**	**794.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
25	**I**	**67.2**	**0.0**	**2,569.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
26	**Total**	**2,700.0**	**2,790.0**	**0.0**	**0.0**	**2,790.0**	**2,520.0**	**2,790.0**	**2,700.0**	**2,790.0**	**2,700.0**	**2,790.0**	**2,790.0**
27													
28	**Monthly Capacity (tons)**												
29		**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
30	**Cap.**	2,700	2,790	2,790	2,520	2,790	2,700	2,790	2,700	2,790	2,790	2,700	2,790
31													
32	**Inventory (ton-months)**												
33	**Prod.**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
34	**A**	0.0	434.8	153.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	**B**	0.0	13.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	**C**	0.0	28.1	0.0	26.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	**D**	0.0	279.2	203.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	**E**	0.0	35.3	0.0	62.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	**F**	0.0	1,237.1	735.9	0.0	0.0	0.0	0.0	191.2	898.0	539.7	0.0	0.0
40	**G**	84.8	142.9	0.0	1,003.5	944.8	987.4	1,369.6	1,352.2	952.4	690.6	396.6	0.0
41	**H**	34.8	0.0	0.0	754.8	709.4	636.2	593.2	527.9	476.4	372.3	294.5	0.0
42	**I**	28.0	0.0	2,559.9	2,547.1	2,528.9	2,506.4	2,494.8	2,392.5	2,222.8	1,869.6	734.3	0.0
43													
44	Total inventory ton-months:												
45				**37,056**									

Thirty-ton Batch Production Plan

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	AltaMetal Ltd. Estimated Monthly Demand (lots)												
2	**Prod**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
3	A	12.6	3.6	9.4	11.4	20.5	26.2	34.3	22.7	13.9	12.9	13.2	18.3
4	B	0.7	0.7	0.4	0.6	0.3	1.7	2.1	0.3	0.4	6.4	4.5	2.4
5	C	1.1	1.4	0.9	1.3	0.9	1.3	0.5	3.4	14.5	20.3	29.9	15.7
6	D	6.7	5.6	2.5	6.8	8.0	8.1	3.4	16.1	17.1	31.0	20.3	18.1
7	E	2.3	2.1	1.2	3.0	2.1	3.0	0.4	3.5	7.6	9.7	8.4	7.8
8	F	14.6	7.2	16.7	24.5	50.3	36.6	27.7	19.2	15.9	24.7	31.6	25.7
9	G	14.4	2.8	11.7	9.7	16.2	11.6	11.9	19.1	13.3	8.7	9.8	18.3
10	H	1.3	1.2	0.5	1.3	1.5	2.4	1.4	2.2	1.7	3.5	2.6	9.8
11	I	1.3	0.9	0.3	0.4	0.6	0.7	0.4	3.4	5.7	11.8	37.8	24.5
12													
13	Daily capacity:		3	lots/day									
14													
15	Production (lots)												
16	**Prod**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
17	**A**	**17**	**0**	**21**	**0**	**20**	**26**	**34**	**37**	**0**	**44**	**0**	**0**
18	**B**	**2**	**0**	**1**	**0**	**0**	**2**	**16**	**0**	**0**	**0**	**0**	**0**
19	**C**	**3**	**0**	**2**	**0**	**1**	**1**	**4**	**0**	**35**	**0**	**46**	**0**
20	**D**	**21**	**0**	**11**	**0**	**0**	**8**	**2**	**53**	**0**	**42**	**0**	**7**
21	**E**	**5**	**0**	**6**	**0**	**4**	**2**	**1**	**0**	**18**	**0**	**8**	**8**
22	**F**	**15**	**7**	**51**	**84**	**53**	**0**	**0**	**0**	**33**	**0**	**26**	**26**
23	**G**	**15**	**60**	**0**	**0**	**15**	**1**	**25**	**0**	**4**	**0**	**10**	**18**
24	**H**	**9**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**10**
25	**I**	**3**	**0**	**1**	**0**	**0**	**50**	**0**	**0**	**3**	**7**	**0**	**24**
26	**Total**	**90**	**67**	**93**	**84**	**93**	**90**	**93**	**90**	**93**	**93**	**90**	**93**
27													
28	Monthly Capacity (lots)												
29		**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
30	**Cap.**	90	93	93	84	93	90	93	90	93	93	90	93
31													
32	Inventory (lot-months)												
33	**Prod**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
34	**A**	4.4	0.8	12.4	1.0	0.6	0.4	0.1	14.5	0.5	31.6	18.3	0.0
35	**B**	1.3	0.6	1.2	0.6	0.3	0.5	14.5	14.2	13.8	7.4	3.0	0.6
36	**C**	1.9	0.5	1.6	0.3	0.5	0.1	3.6	0.2	20.7	0.4	16.4	0.8
37	**D**	14.3	8.7	17.2	10.4	2.4	2.3	0.9	37.8	20.7	31.7	11.4	0.3
38	**E**	2.7	0.6	5.4	2.4	4.3	3.3	3.9	0.4	10.8	1.2	0.7	1.0
39	**F**	0.4	0.2	34.5	94.0	96.7	60.1	32.4	13.2	30.3	5.6	0.0	0.3
40	**G**	0.6	57.8	46.1	36.4	35.2	24.6	37.6	18.5	9.2	0.5	0.7	0.4
41	**H**	7.7	6.5	6.0	4.7	3.2	0.8	10.3	8.2	6.4	3.0	0.4	0.6
42	**I**	1.7	0.8	1.5	1.0	0.4	49.7	49.3	45.9	43.2	38.4	0.6	0.1
43													
44	Total inventory ton-months:												
45				**39,291**									

JIT vs. 30-ton-lots:

	JIT	30-ton-lots
# of different products per month		
Smallest lot:		
Total inventory (ton-months)		(% higher)

DISTRIBUTION PLANNING

Introduction

Most companies need a **distribution system**, whose purpose it is to either move the company's **products to markets**, or to move necessary **raw materials to** the company's **facilities**, or both.

Total distribution costs are often a large percentage of a firm's costs, especially in a sparsely populated country such as Canada.

Many decisions affect distribution costs. One way to classify them is:

1. What should the overall structure of the distribution system be?

As an example, the distribution system could be centralized and three-tiered, with one national distribution center, several regional and many local distribution centers. Or, it could be decentralized.

2. Where should inventories of products or raw materials be stored?
3. How much inventory of each product and raw material should be stored at each location? For example, in a three-tiered system, commonly used parts might be stocked at local distribution centers while parts that are rarely needed would be ordered from a regional or national distribution center when needed.

4. How should the flow of products and raw materials through the distribution system be coordinated?
5. What modes of transportation should be used? Air, train, or truck? Using the company's own vehicles or not?

If you want to know everything about designing and controlling a distribution system, then take more courses! In this course, we will mostly talk about a few idealized distribution situations and simple (but powerful) tools that can be used to reduce distribution costs in those situations. But the tools can also be used as building blocks to tackle more realistic and complicated situations.

Red Dog Beer Company

Current Facility	Offer ($/yr)	Capacity (truckl./yr)	Prod'n Cost ($/truckl.)
Calgary	200,000	2,400	515

Facility	Cap. + oper. cost ($/yr)	Capacity (truckl./yr)	Prod'n Cost ($/truckl.)
Edmonton	460,000	2,750	410
Calgary (new)	615,000	2,900	380
Red Deer	160,000	715	450
Lethbridge	150,000	650	460

- Transportation cost = $1/truckload/km
- Demand = 1 truckload/1,000 people/year

Possible Configurations

	Annual costs			
Configuration	**Cap.+ oper.**	**Transport**	**Prod'n**	**Total**
All 4 new	?	?	?	?
Only Edm	?	?	?	?
Status Quo	?	?	?	?
…				

A Transportation Problem

The Rent-A-Dent car rental company allows its customers to pick up a rental car at one location and return it to *any* of its locations. Currently, two locations (Edmonton and Calgary) have 15 and 18 surplus cars, respectively, and four locations (Vancouver, Red Deer, Drumheller, and Jasper) need 10, 10, 10, and 3 cars, respectively. The costs of getting the surplus cars from locations 1 and 2 to the other locations are summarized below.

	Costs of Transporting Cars Between Locations ($ per car)				
	3: Vancouver	4: Red Deer	5: Drumheller	6: Jasper	Cars Available
1: Edmonton	54	17	23	30	15
2: Calgary	24	18	19	31	18
Cars Needed	10	10	10	3	

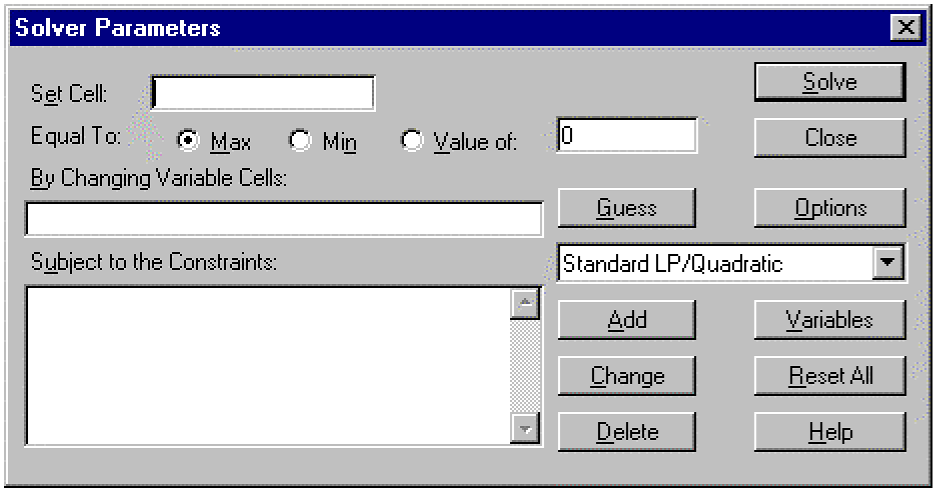
Rent-A-Dent wants to transport cars from the surplus locations to the locations that need cars at the lowest possible cost.

Solving Rent-A-Dent's Problem Using Excel:

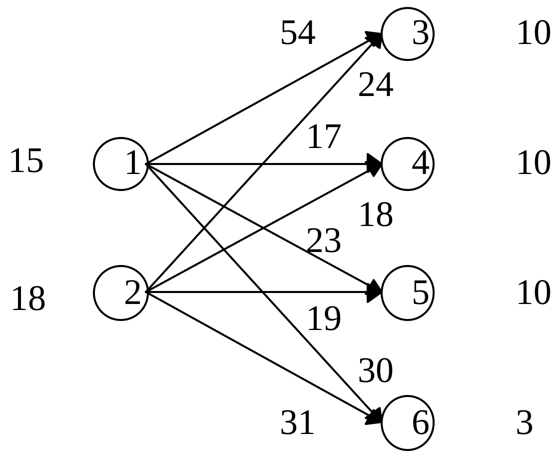
	A	B	C	D	E	F	G	H
1			Rent-A-Dent					
2								
3			Transportation Costs ($ per car):					
4			3	4	5	6		
5		1	54	17	23	30		
6		2	24	18	19	31		
7								
8								
9			Cars Transported to Location:				Cars	Cars
10			3	4	5	6	Used	Available
11		1	0	0	0	0	0	15
12		2	0	0	0	0	0	18
13		Assigned	0	0	0	0		
14		Needed	10	10	10	3		
15								
16		Total Transportation Cost ($):				0		

Total transportation cost if a "greedy" method is used to allocate cars: __________

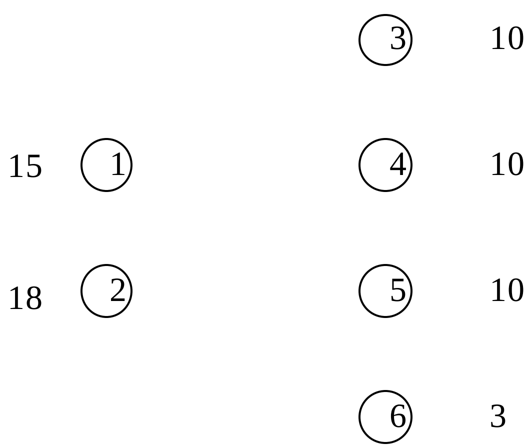
Lowest possible transportation cost: _________



Rent-A-Dent's problem can be represented graphically, on a **network**:



The optimal solution is:



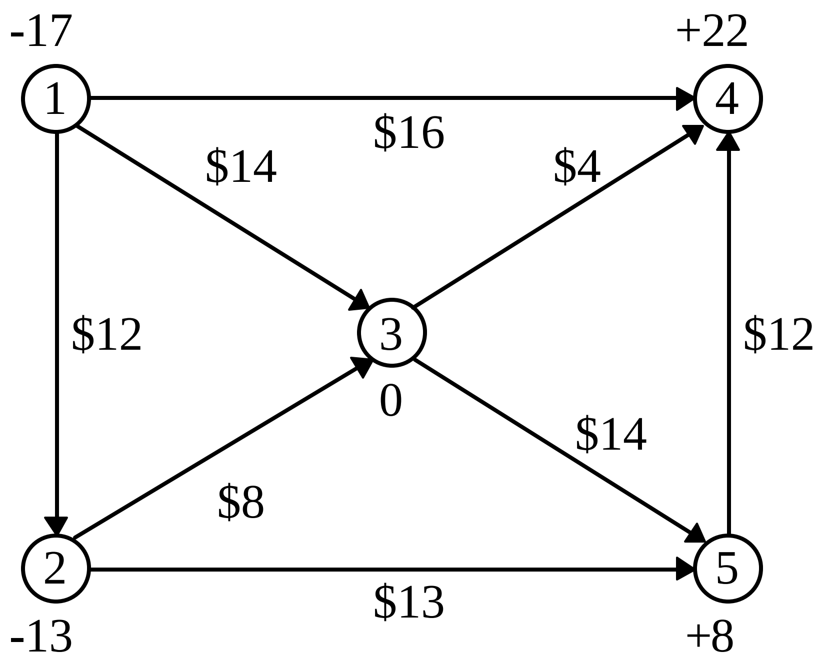
Rent-A-Dent's problem of transporting cars between rental locations is an example of a **transportation problem**, with two **supply nodes** (locations 1 and 2), each of which has a given **supply** (# of surplus cars), and four **demand nodes** (locations 3, 4, 5, and 6), each of which has a given **demand** (# of cars needed). Also given are the **transportation costs per unit** (unit = 1 car) from any supply node to any demand node.

The problem is to send flow from the supply nodes to the demand nodes so that demand is satisfied and supply is not exceeded, at the lowest total cost.

In the Rent-A-Dent problem, every node was either a supply node (flow only goes out) or a demand node (flow only goes in). Sometimes it is more natural to include **transhipment nodes**, where flow can go both in and out of the node. For example, we might include Kamloops in the network, to explicitly model the possibility of transporting cars from Edmonton to Vancouver, *via* Kamloops. In that case, we need to solve ...

A Minimum Cost Flow Problem

An oil company needs to pump oil from two oilfields (nodes 1 and 2) to two refineries (nodes 4 and 5). The pipeline network is shown below, with the two oilfields, the two refineries, and one switching point (node 3). The pumping costs for each pipeline are shown, in units of dollars per thousand barrels of oil. The capacity of each of the pipelines shown is ten thousand barrels per day.



The negative numbers next to nodes indicate supply: There are 17 thousand barrels available at node 1 and 13 thousand barrels available at node 2. The positive numbers next to nodes indicate demand: 22 thousand barrels are needed at node 4 and 8 thousand barrels are needed at node 5. The zero next to node 3 means that no oil is available and no oil is needed at node 3. However, oil can be pumped *through* node 3.

The company needs to pump the oil from the oilfields to the refineries and it has one day to do this.

Using Excel to Solve the Problem - Take One

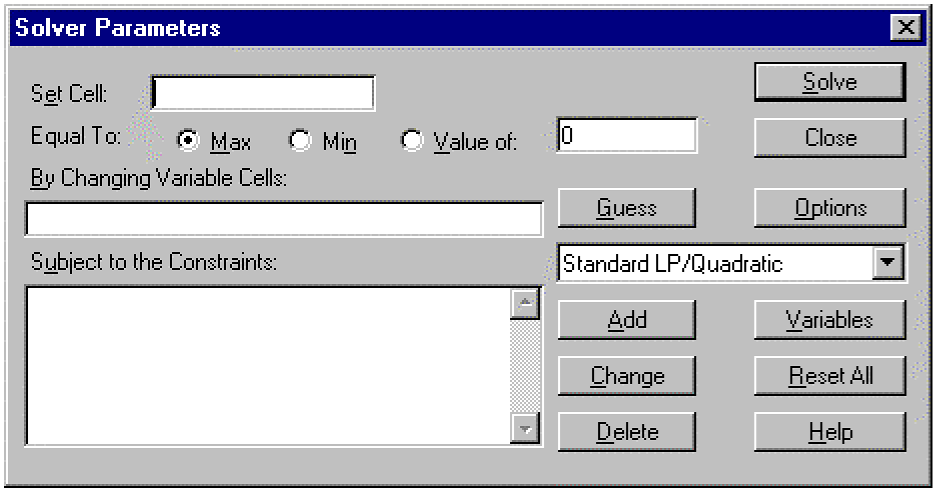
	A	B	C	D	E	F	G
1	**Quantity Pumped:**		**Oil Pipelines**				
2							
3	**From: To:**	**1**	**2**	**3**	**4**	**5**	**Total Out**
4	**1**		0	0	0		0
5	**2**			0		0	0
6	**3**				0	0	0
7	**4**						0
8	**5**				0		0
9	**Total In**	0	0	0	0	0	
10							
11	**Tot. In - Tot. Out**	0	0	0	0	0	
12	**Supply/Demand**	-17	-13	0	22	8	
13							
14	**Unit Pumping Costs:**				**Total Cost:**		$0
15							
16	**From: To:**	**1**	**2**	**3**	**4**	**5**	
17	**1**		$12	$14	$16		
18	**2**			$8		$13	
19	**3**				$4	$14	
20	**4**						
21	**5**				$12		

Key cell formulas:

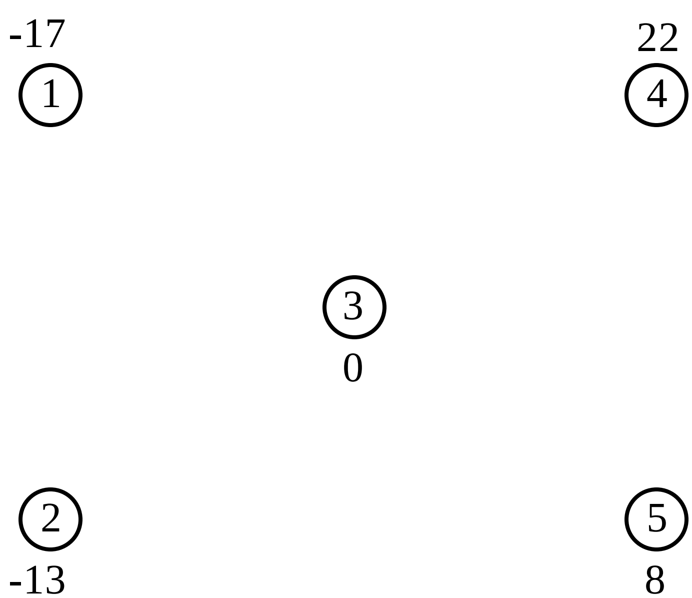
Cell	Formula	Propagated to:
B9	=SUM(B4:B8)	C9:F9
B11	=B9 - G4	similar formulas in C11:F11
G4	=SUM(B4:F4)	G5:G8
G14	=SUMPRODUCT(B4:F8,B17:F21)	-

Darkened cells represent arcs that are missing.

Settings in Solver Dialog box:



The solution:



Problem with this approach:
Entry of “changing cells” very cumbersome and prone to error.

Using Excel to Solve the Problem - Take Two

The problem with the previous approach can be overcome by using a **node-arc incidence matrix**. This matrix has one row for every arc and one column for every node. The entries in the matrix are either zero, -1, or +1. The node-arc incidence matrix for the pipeline network is:

Arcs		Nodes				
From	To	1	2	3	4	5
1	2	-1	1	0	0	0
1	3	-1	0	1	0	0
1	4	-1	0	0	1	0
2	3					
2	5					
3	4					
3	5					
5	4					

For every arc, there is

- a “-1” for the “From” node,
- a “+1” for the “To” node, and
- zeros everywhere else.

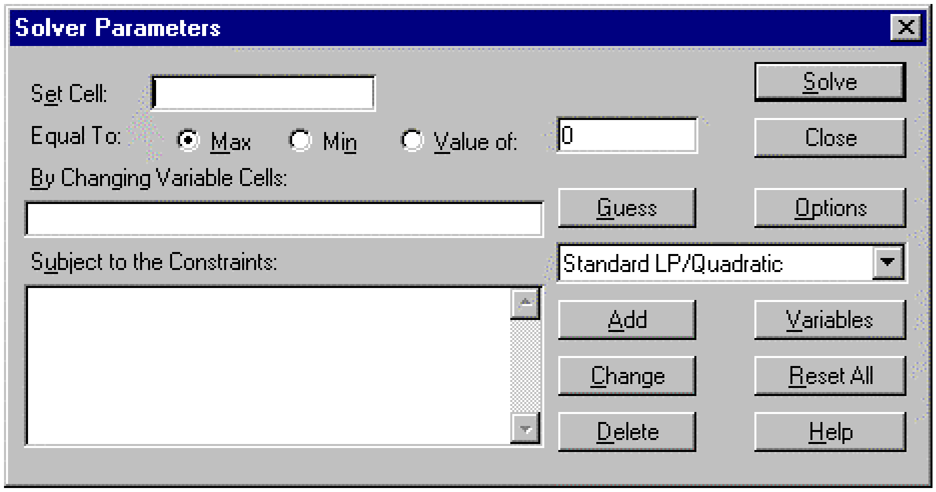
Excel can generate this matrix, once the first two columns have been entered:

	A	B	C	D	E	F	G	H	I
1			**Oil Pipelines**						
2									
3		**-- Arcs --**		**Unit**	**------- Nodes --------**				
4	**Pump:**	**From:**	**To:**	**Cost**	**1**	**2**	**3**	**4**	**5**
5	1	1	2	$12	-1	1	0	0	0
6	0	1	3	$14	-1	0	1	0	0
7	0	1	4	$16	-1	0	0	1	0
8	0	2	3	$8	0	-1	1	0	0
9	0	2	5	$13	0	-1	0	0	1
10	0	3	4	$4	0	0	-1	1	0
11	0	3	5	$14	0	0	-1	0	1
12	0	5	4	$12	0	0	0	1	-1
13		**Total Cost:**		$12					
14		**Flow in - Flow out:**			-1	1	0	0	0
15		**Demand - Supply:**			-17	-13	0	22	8

Key cell formulas:

Cell	Formula	Propagated to:
E5	=IF($B5=E$4,-1,IF($C5=E$4,1,0))	F5:I5; then E6:I12
D13	=SUMPRODUCT(D5:D12,$A$5:$A$12)	
E14	=SUMPRODUCT(E5:E12,$A$5:$A$12)	F14:I14

Settings in Solver Dialog box:



To recap: The **minimum cost flow problem** is to minimize the total cost of sending flow through a network, subject to the following constraints:

- Flow conservation: the flow into a node must equal the flow out of a node (including supply or demand, i.e., flow from or to outside the network).
- There may be capacity constraints on the arcs (no more than 10 thousand barrels on any arc in the example).
- The flow along an arc can never be negative.

Shortest Path Problem

The Henderson Food Company needs to ship a truckload of Taber Corn from its warehouse in Lethbridge to a distributor in Fort McMurray as soon as possible. The travel times between various towns are:

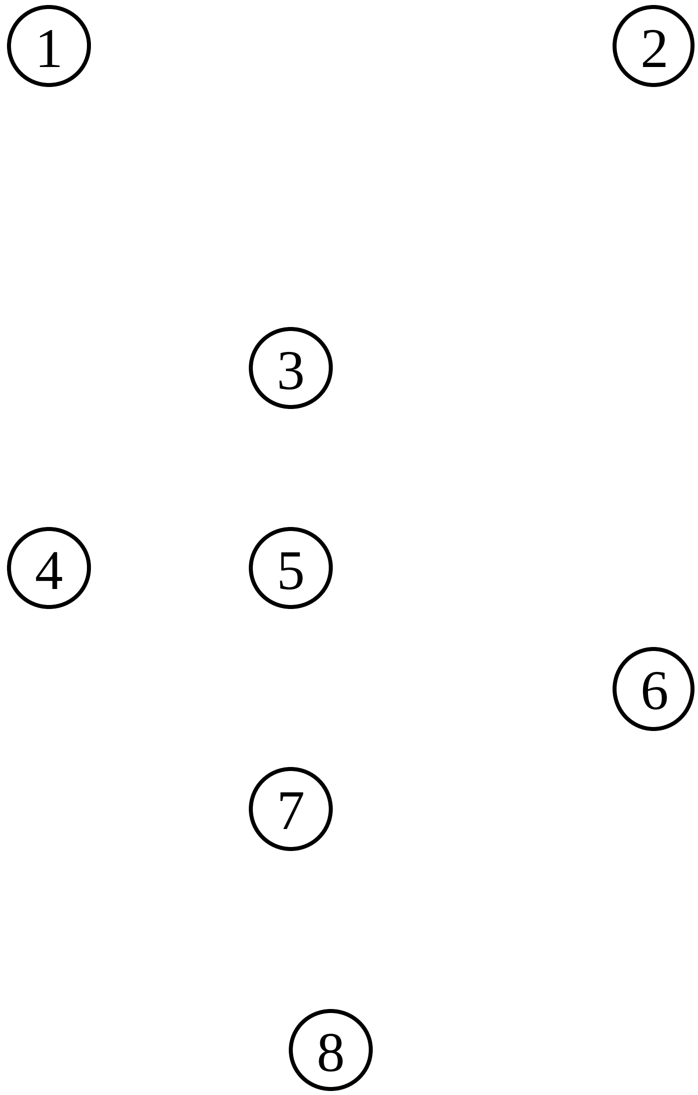
(hours)	To:							
From:	FM	GP	EDM	RMH	RD	DR	CAL	LET
Ft. McMurray		10.3	5.9			9.8		
Gr. Prairie	10.3		6.0	6.3				
Edmonton	5.9	6.0		2.5	1.6	3.9		
Rocky Mntn House		6.3	2.5		1.2	3.4	2.6	
Red Deer			1.6	1.2		2.3	1.8	
Drumheller	9.8		3.9	3.4	2.3		1.6	3.7
Calgary				2.6	1.8	1.6		2.8
Lethbridge						3.7	2.8	

Finding the fastest route from Lethbridge to Fort McMurray can be viewed as a minimum cost flow problem: we need to push one unit of flow into the network in Lethbridge and pull one unit of flow out of the network in Fort McMurray, and we need to do so at the lowest possible cost (=time). All other towns will have a net supply/demand of zero.

The solution to the problem, from Excel, is:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1					**Henderson Food Company**									
2														
3									**------------ Nodes ------------**					
4			**Route**				**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5	**Select:**		**From:**		**To:**	**Time**	FM	GP	EDM	RMH	RD	DR	CAL	LET
6	0	1	FM	2	GP	10.3	-1	1	0	0	0	0	0	0
7	0	1	FM	3	EDM	5.9	-1	0	1	0	0	0	0	0
8	0	1	FM	6	DR	9.8	-1	0	0	0	0	1	0	0
9	0	2	GP	1	FM	10.3	1	-1	0	0	0	0	0	0
10	0	2	GP	3	EDM	6.0	0	-1	1	0	0	0	0	0
11	0	2	GP	4	RMH	6.3	0	-1	0	1	0	0	0	0
12	1	3	EDM	1	FM	5.9	1	0	-1	0	0	0	0	0
13	0	3	EDM	2	GP	6.0	0	1	-1	0	0	0	0	0
14	0	3	EDM	4	RMH	2.5	0	0	-1	1	0	0	0	0
15	0	3	EDM	5	RD	1.6	0	0	-1	0	1	0	0	0
16	0	3	EDM	6	DR	3.9	0	0	-1	0	0	1	0	0
17	0	4	RMH	2	GP	6.3	0	1	0	-1	0	0	0	0
18	0	4	RMH	3	EDM	2.5	0	0	1	-1	0	0	0	0
19	0	4	RMH	5	RD	1.2	0	0	0	-1	1	0	0	0
20	0	4	RMH	6	DR	3.4	0	0	0	-1	0	1	0	0
21	0	4	RMH	7	CAL	2.6	0	0	0	-1	0	0	1	0
22	1	5	RD	3	EDM	1.6	0	0	1	0	-1	0	0	0
23	0	5	RD	4	RMH	1.2	0	0	0	1	-1	0	0	0
24	0	5	RD	6	DR	2.3	0	0	0	0	-1	1	0	0
25	0	5	RD	7	CAL	1.8	0	0	0	0	-1	0	1	0
26	0	6	DR	1	FM	9.8	1	0	0	0	0	-1	0	0
27	0	6	DR	3	EDM	3.9	0	0	1	0	0	-1	0	0
28	0	6	DR	4	RMH	3.4	0	0	0	1	0	-1	0	0
29	0	6	DR	5	RD	2.3	0	0	0	0	1	-1	0	0
30	0	6	DR	7	CAL	1.6	0	0	0	0	0	-1	1	0
31	0	6	DR	8	LET	3.7	0	0	0	0	0	-1	0	1
32	0	7	CAL	4	RMH	2.6	0	0	0	1	0	0	-1	0
33	1	7	CAL	5	RD	1.8	0	0	0	0	1	0	-1	0
34	0	7	CAL	6	DR	1.6	0	0	0	0	0	1	-1	0
35	0	7	CAL	8	LET	2.8	0	0	0	0	0	0	-1	1
36	0	8	LET	6	DR	3.7	0	0	0	0	0	1	0	-1
37	1	8	LET	7	CAL	2.8	0	0	0	0	0	0	1	-1
38			**Total time:**			12.1								
39			**Flow in - Flow out:**				1	0	0	0	0	0	0	-1
40	**Origin (-1)/Destination (+1):**						1	0	0	0	0	0	0	-1

The fastest route from Lethbridge to Fort McMurray is:



Handling Additional Requirements on the Route:

What if we are interested in the quickest route from Lethbridge to Fort McMurray that

- goes through Rocky Mountain House?

- does not go through Calgary?

- includes the Drumheller-Red Deer arc?

- Suppose you are interested in the shortest way from Lethbridge to Fort McMurray, not the fastest way. What do you do?

INVENTORY MANAGEMENT

Introduction

Inventory = goods that have not yet been sold (raw mat'l., work-in-process, finished goods, supplies)

Inventories in Canada

Year	Total inventory	% of GDP	Total inventory/ monthly shipments
1985	$37 B	7.8%	1.7
1990	$45 B	6.7%	1.6
1995	$52 B	6.7%	1.4

Why keep inventory?

1) Meet customer demand

- demand is unpredictable
- delivery takes time
- there is a fixed cost for each delivery

2) Decouple stages

- production disruptions
- demand fluctuations
- production scale economies

3) Volume discounts

Factors involved in inventory management

Relevant questions

- *When* to order? (ROP = reorder point)
- *How much* to order? (Q = reorder quantity)

Relevant costs

- *Item cost* (cost of goods)
- *Ordering costs* (the cost incurred each time an order is placed)
  - ∗ clerical and retrieval expenses
  - ∗ delivery, inspection
  - ∗ setup (if produced in house)
- *Carrying costs* (associated with storing items)
  - ∗ opportunity cost of capital
  - ∗ insurance
  - ∗ shrinkage, spoilage, obsolescence
  - ∗ material handling (fork lifts, storage space)
- *Shortage costs* (cost of running out of item)
  - ∗ lost goodwill (or discounts and penalty)
  - ∗ lost sales
  - ∗ shut down of assembly line (production process)

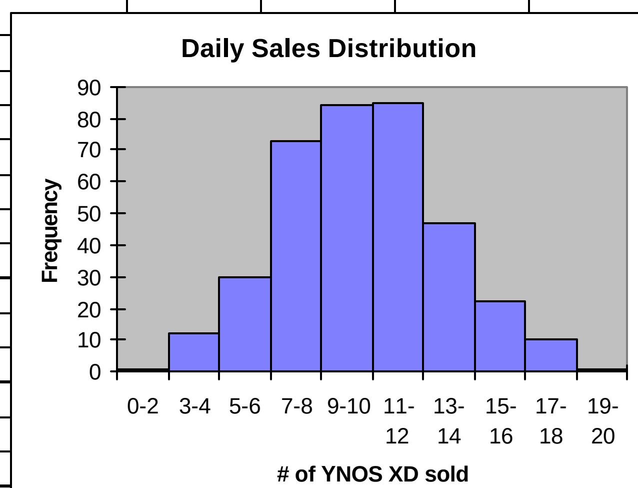
A&E Noise

A&E Noise is a chain of electronics stores with several stores in the Edmonton area. Their inventory policy for the YNOS XD, their most popular VCR model, is under review.

Daily Sales Distribution

The spreadsheet below shows daily sales in the Edmonton area of the YNOS XD over a 365-day period.

	A	B	C	D	E	F	G	H	I	J	K
1	**YNOS XD Sales -- Edmonton area**										
2											
3	**Date**	**# Sold**		**Summary Statistics**							
4	05-Feb-98	6			**Average**	10.12					
5	06-Feb-98	11			**Std. Deviation**	3.16					
6	07-Feb-98	12			**Min**	2					
7	08-Feb-98	13			**Max**	19					
8	09-Feb-98	8									
9	10-Feb-98	9		**# Sold**		**Frequency**					
10	11-Feb-98	9		0-2	2	1					
11	12-Feb-98	7		3-4	4	12					
12	13-Feb-98	12		5-6	6	30					
13	14-Feb-98	11		7-8	8	73					
14	15-Feb-98	11		9-10	10	84					
15	16-Feb-98	8		11-12	12	85					
16	17-Feb-98	8		13-14	14	47					
17	18-Feb-98	8		15-16	16	22					
18	19-Feb-98	6		17-18	18	10					
19	20-Feb-98	13		19-20	20	1					
20	21-Feb-98	11									
367	03-Feb-99	11									
368	04-Feb-99	6									



How the histogram (“Daily Sales Distribution”) was generated:

1. Type the numbers shown in cells E10:E19.
2. Highlight the region F10:F19. Then type
   `=FREQUENCY(B4:B368,E10:E18)`
   and then press the <ctrl>,<shift> and <enter> keys simultaneously.

Note:

- The two arguments of the `FREQUENCY` function are the `data` (`B4:B368`) and the `bins` (`E10:E18`).
- The `bins` should have one fewer cells than the number of frequency categories desired.
- Examples:
  - The number in cell F12 is the number of days on which sales were strictly greater than 4 (cell E11) and less than or equal to 6 (cell E12).
  - The number in cell F19 is the number of days on which sales were greater than 18 (cell E18).

Other Relevant Data

A&E Noise orders their VCRs from a supplier in Vancouver. They purchase each YNOS XD for $150 (including shipping). In addition, the supplier charges a $20 handling fee per order. The supplier guarantees delivery in 5 days. Jane Wu, one of A&E Noise's management trainees, prepares orders. Each hour of her time costs A&E Noise $20. She usually spends about 30 minutes in total on the paperwork and phone calls needed to place an order.

A&E Noise sells each YNOS XD for $175. According to corporate policy, at least 95% of customer demand for each VCR model should be met from stock (including transfer from another Edmonton-area store). A&E Noise's accounting department has estimated that the marginal cost of keeping one dollar's worth of inventory in stock for a year is about 25 cents. This includes the cost of the capital invested in the inventory and the cost of storage facilities.

Therefore,

- cost of holding one YNOS XD in inventory for one year = ?
- cost of holding one YNOS XD for one day = ?

  (Note that A&E Noise and its Vancouver supplier both operate 365 days a year)

Current inventory policy

Jane Wu's job for the past 3 months has been to place orders for YNOS XDs (and other products). Every day, she queries the company's inventory tracking system for the total number of YNOS XDs in stock in the Edmonton area. To this number she adds the number of YNOS XDs currently in transit to Edmonton. The total is known as the ***inventory position*** (I). Whenever I $\leq$ 60 units (the ***reorder point***, ROP), Jane places an order for 80 more units (the ***order quantity***, Q).

Example:

1. Today is 21 August, 1997, and there are 50 units in stock. The last two orders placed by Jane were on 9 August and 18 August. Should Jane order today?

2. Today is 15 September, 1997, and there are 55 units in stock. The last order placed was on 5 September. Should Jane order today?

Inventory Costs

Jane wonders whether she could save money for A&E Noise by changing the reorder point or the order quantity. As a first step, she decides to calculate the inventory costs associated with YNOS XD under the current policy.

Item Costs

Total units sold per year ≈

Total item costs per year ≈

Total item costs per year if order size were changed to 90 ≈

Order Costs

Cost per order =

Number of orders per year ≈

Total order cost per year ≈

Holding costs

Minimum inventory ≈

Maximum inventory ≈

Average inventory ≈

Total unit-years of inventory per year ≈

Total holding cost per year ≈

Simulation of Inventory Policy

	A	B	C	D	E	F	G	H	I	J	K
1	**YNOS XD Sales -- Edmonton area**								**Net revenue**		$ 91,000
2									**Order cost**		$ 1,380
3	**ROP**	**60**	**S**	**$ 30.00**	per order				**Holding cost**		$ 1,526.82
4	**Q**	**80**	**H**	**$ 0.10**	per item per day					**Net profit**	$ 88,093
5			**Revenue-COGS**	**$ 25.00**	per item sold						
6										**Fill rate**	98.5%
7	**Date**	**Demand**	**Beginning inventory**	**Inventory position**	**Order**	**Sales**	**Shortage**	**Ending inventory**	**Net revenue**	**Order cost**	**Holding cost**
8											
9											
10											
11											
12								55			
13	05-Feb-98	6	55	55	80	6	0	49	$ 150	$ 30	$ 5.03
14	06-Feb-98	11	49	129	0	11	0	38	$ 275	$ -	$ 3.90
15	07-Feb-98	12	38	118	0	12	0	26	$ 300	$ -	$ 2.67
16	08-Feb-98	13	26	106	0	13	0	13	$ 325	$ -	$ 1.34
17	09-Feb-98	8	13	93	0	8	0	5	$ 200	$ -	$ 0.51
18	10-Feb-98	9	85	85	0	9	0	76	$ 225	$ -	$ 7.81
19	11-Feb-98	9	76	76	0	9	0	67	$ 225	$ -	$ 6.88
20	12-Feb-98	7	67	67	0	7	0	60	$ 175	$ -	$ 6.16
21	13-Feb-98	12	60	60	80	12	0	48	$ 300	$ 30	$ 4.93
22	14-Feb-98	11	48	128	0	11	0	37	$ 275	$ -	$ 3.80
23	15-Feb-98	11	37	117	0	11	0	26	$ 275	$ -	$ 2.67
24	16-Feb-98	8	26	106	0	8	0	18	$ 200	$ -	$ 1.85
25	17-Feb-98	8	18	98	0	8	0	10	$ 200	$ -	$ 1.03
26	18-Feb-98	8	90	90	0	8	0	82	$ 200	$ -	$ 8.42
27	19-Feb-98	6	82	82	0	6	0	76	$ 150	$ -	$ 7.81
28	20-Feb-98	13	76	76	0	13	0	63	$ 325	$ -	$ 6.47
29	21-Feb-98	11	63	63	0	11	0	52	$ 275	$ -	$ 5.34
30	22-Feb-98	14	52	52	80	14	0	38	$ 350	$ 30	$ 3.90

	A	B	C	D	E	F	G	H	I	J	K
374	01-Feb-99	7	50	50	80	7	0	43	$ 175	$ 30	$ 4.42
375	02-Feb-99	11	43	123	0	11	0	32	$ 275	$ -	$ 3.29
376	03-Feb-99	11	32	112	0	11	0	21	$ 275	$ -	$ 2.16
377	04-Feb-99	6	21	101	0	6	0	15	$ 150	$ -	$ 1.54
378											
379	**Totals**	3695				3640			$ 91,000	$ 1,380	$ 1,526.82

Cell:	Formula:	Propagated to:
C13	=H12+E8	C14:C377
D13	=C13+SUM(E9:E12)	D14:D377
E13	=IF(D13<=ROP,Q,0)	E14:E377
	Note: ROP and Q are "names;" they refer to cells B3 and B4	
F13	=IF(B13<=C13,B13,C13)	F14:F377
G13	=B13-F13	G14:G377
H13	=C13-F13	H14:H377
I13	=NR*F13 (Note: NR is a name; it refers to cell D5)	I14:I377
J13	=S*IF(E13>0,1,0) (Note: S is a name; it refers to cell D3)	J13:J377
K13	=H*H13 (Note: H is a name; it refers to cell D4)	K13:K377
K6	=F379/B379	-

Using Tables to experiment with policies

	L	M	N	O	P	Q	R
9		**Net Profit**			**Order Quantity**		
10		###	**60**	**70**	**80**	**90**	**100**
11	**Reorder**	**50**	$ 81,696	$ 83,472	$ 82,785	$ 83,446	$ 85,381
12	**Point**	**60**	$ 88,242	$ 88,169	$ 88,093	$ 89,048	$ 88,780
13		**70**	$ 89,011	$ 89,098	$ 88,881	$ 89,078	$ 88,723
14		**80**	$ 88,697	$ 88,687	$ 88,752	$ 88,782	$ 88,642
15		**90**	$ 88,278	$ 88,313	$ 88,382	$ 88,375	$ 88,241

Procedure to generate the above table

(the table contains the results of (5)(5) = 25 runs of the model on the previous page – each run being a 365 day simulation of a particular inventory policy (Q,ROP)).

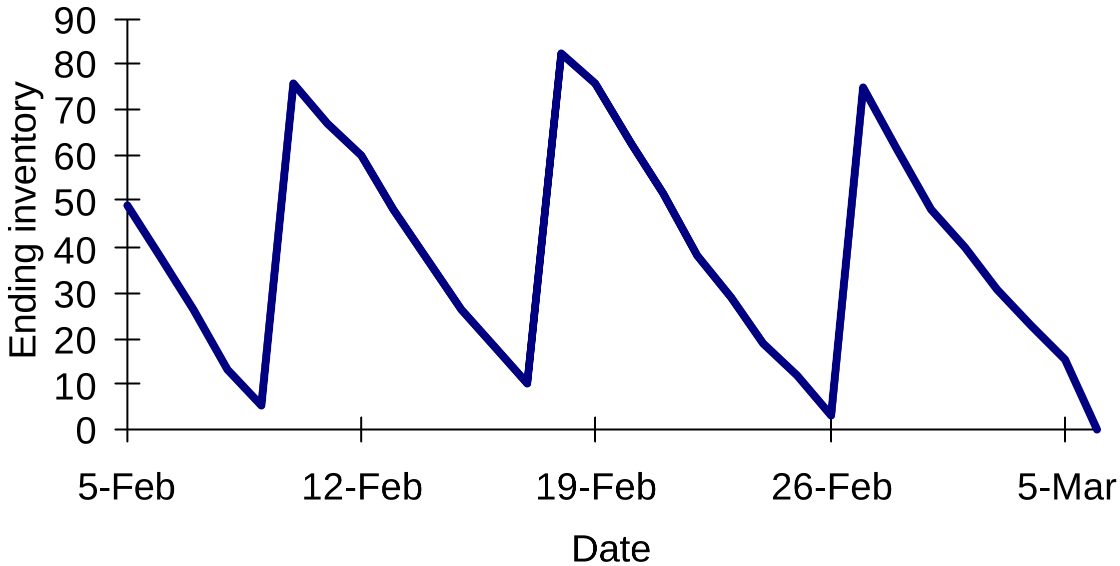
1. Type trial values of reorder point in column M (rows 11 to 15 in this case).
2. Type trial values of order quantity in row 10 (columns N to R in this case).
3. Type "=K4" in cell M10 (net profit cell)
4. Select the whole table (drag across it) -M10:R15
5. Go to Data menu and select "Table."
6. In response to dialog box, set row input cell to B4 and column input cell to B3. Click OK.

The table will now fill in with the net profits for each combination of Q and ROP.

The policy that gives the highest net profit is:

The EOQ Formula

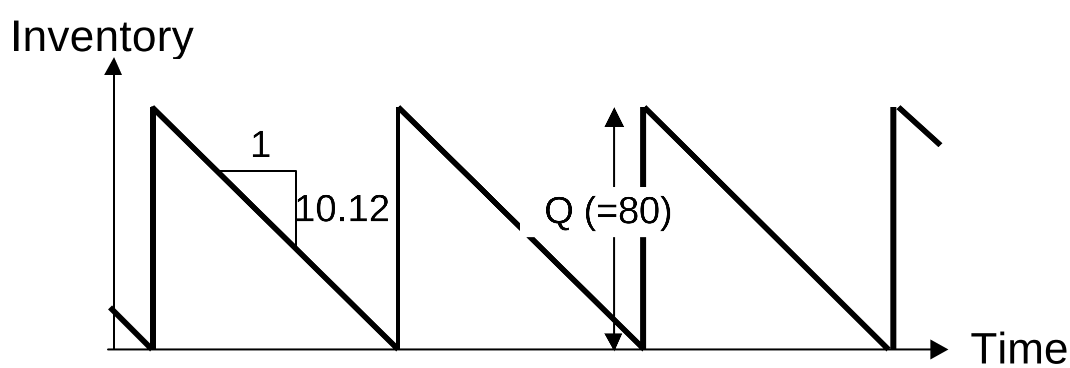
The “inventory profile” for the first 30 days of the simulation looks as follows:



Approximations:

- Demand is constant
- Inventory drops to zero just before an order arrives

Approximate inventory profile:



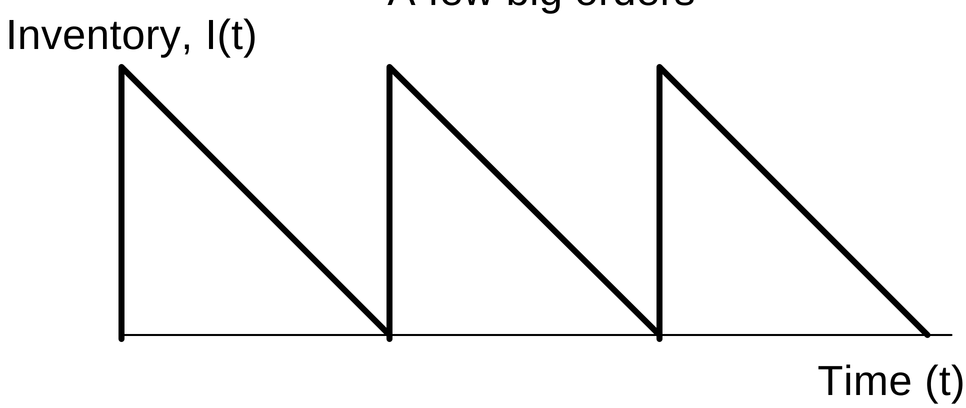
Objective: minimize total costs, where

total cost	=	item cost + order cost + carrying cost + shortage cost
relevant cost	=	costs which depend on order size and frequency
	=	order cost + carrying cost

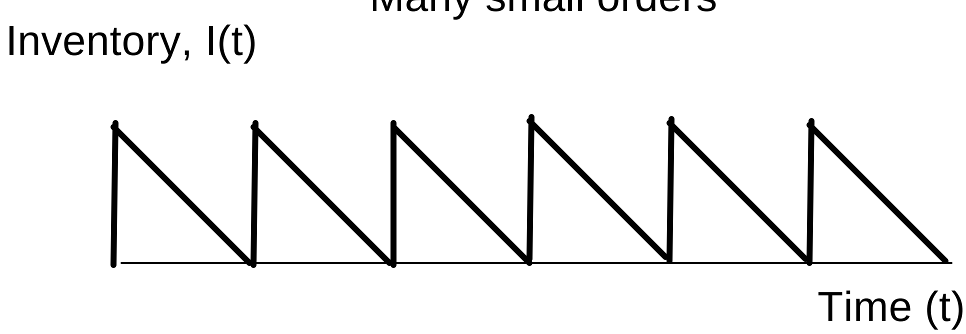
The basic trade-off:

		Then: order cost	Then: carrying cost
If:	order large quantities few times	LOW	HIGH
If:	order small quantities many times	HIGH	LOW

A few big orders



Many small orders



Definitions

Parameters	*Variables*
S = order cost (per order)	Q = order quantity
H = carrying cost (per item per year)	N = number of orders/year
D = annual demand	I_{avg} = average inventory

(time unit is assumed to be one year, but could be a month, a day, etc., as long as consistency is maintained)

EOQ Formula Derivation

$$\text{Relevant cost} = \text{ordering cost} + \text{carrying cost}$$

$$RC = S*N + H*(I_{avg})$$

$$RC(Q) = S*(D/Q) + H*(Q/2)$$

(since: $\text{Number of orders} = \dfrac{\text{Annual demand}}{\text{Order quantity}}$ and

$\text{Average inventory} = \dfrac{\text{Order quantity}}{2}$)

$$Q^* = \sqrt{\frac{2DS}{H}} \quad \text{(... through the magic of calculus)}$$

A&E Noise YNOS XD

D = 10.12 units/day, S = $30/order, H = $0.10/day

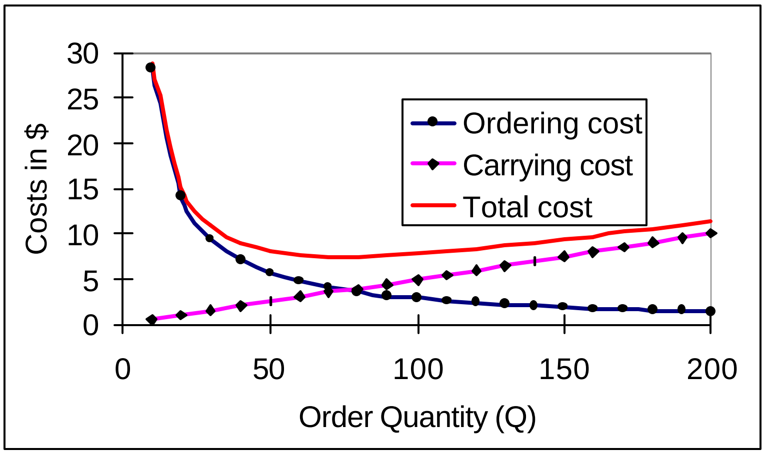
⇒ Q* = 78 units, N* = 10.12/78 = 0.13 turns/day = 47.4 turns/year, or order every 365/47.4 = 8 days.

Relevant cost is: RC (Q*) = $7.79/day = $2844.19/year.

If the lead time is 5 days, order with 5*(10.12) ≈ 51 units in stock.

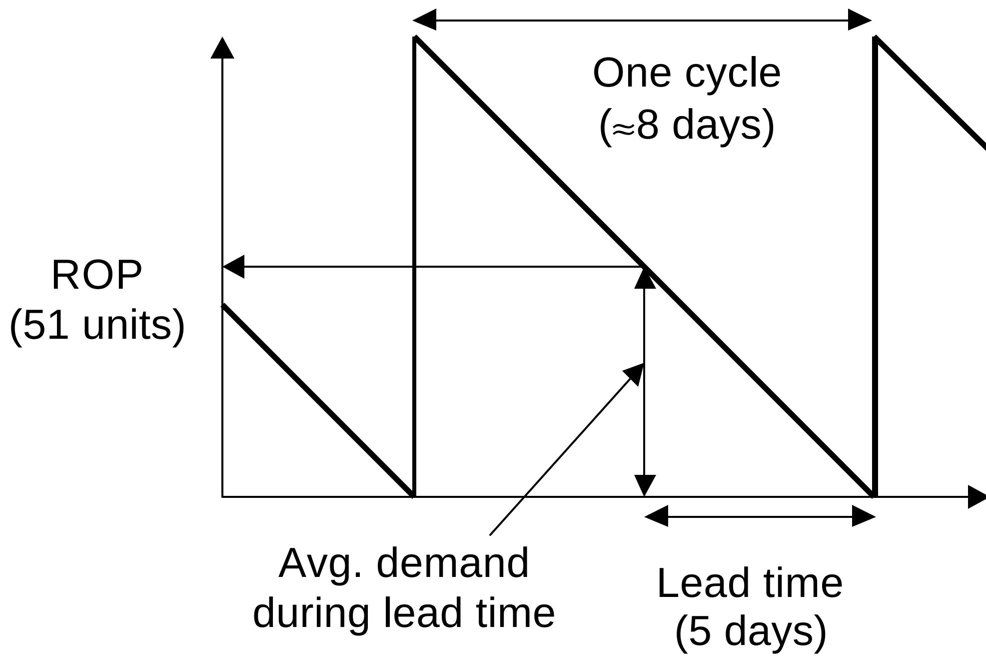
Spreadsheet implementation of EOQ model

	A	B	C	D
1	Data for Spreadsheet Implementation of EOQ			
2	Demand (units/day):		10.12	D
3	Ordering cost ($/order):		$ 30.00	S
4	Holding cost ($/unit-day):		$ 0.10	H
5	Lead time (days):		5	
6	Item cost ($/item):		$ 150.00	
7				
8	Total annual inventory cost = Ordering cost + Carrying cost			
9				
10	Q	(D/Q)*S	(Q/2)*H	
11	**Order quantity**	**Ordering cost**	**Carrying cost**	**Total cost**
12	**10**	30.37	0.50	30.87
13	**20**	15.18	1.00	16.18
14	**30**	10.12	1.50	11.62
15	**40**	7.59	2.00	9.59
16	**50**	6.07	2.50	8.57
17	**60**	5.06	3.00	8.06
18	**70**	4.34	3.50	7.84
19	**80**	3.80	4.00	7.80
20	**90**	3.37	4.50	7.87
21	**100**	3.04	5.00	8.04
22	**110**	2.76	5.50	8.26
23	**120**	2.53	6.00	8.53
24	**130**	2.34	6.50	8.84
25	**140**	2.17	7.00	9.17
26	**150**	2.02	7.50	9.52
27	**160**	1.90	8.00	9.90
28	**170**	1.79	8.50	10.29
29	**180**	1.69	9.00	10.69
30	**190**	1.60	9.50	11.10
31	**200**	1.52	10.00	11.52

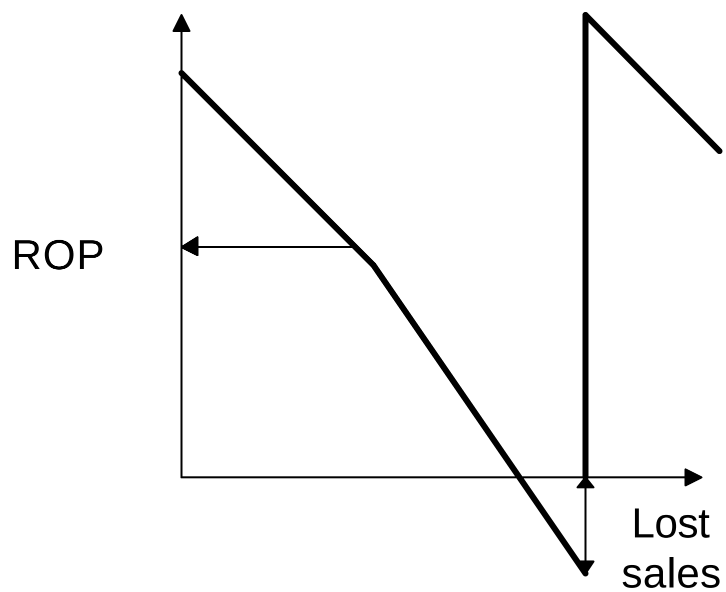


Shortages

"**Average case**":



Higher than average demand during leadtime:



How to reduce probability of a shortage:

To quantify the risk of shortages, we need to consider how much demand occurs during the leadtime (while we are waiting for the order to arrive).

To do this, we go back to the sales data and we ask:

- If we placed an order on 5 Feb, then how much demand would occur while we wait for the order to arrive (i.e., from 5 Feb to 9 Feb)?
- If we placed an order on 6 Feb, then how much demand would occur while we wait for the order to arrive (i.e., from 6 Feb to 10 Feb)?
- And so on …

The worksheet below answers these what-if questions.

	A	B	C	D	E	F	G	H	I
1	**YNOS XD Sales -- Edmonton area**						**ROP**	**60**	
2							**Leadtime**	**5**	
3	**From**	**To**	**demand during leadtime**	**shortage**			**Q**	80	
4	05-Feb-98	09-Feb-98	50	0		**Demand during Leadtime**			
5	06-Feb-98	10-Feb-98	53	0			**Average**	50.68	
6	07-Feb-98	11-Feb-98	51	0			**Std. Deviation**	6.29	
7	08-Feb-98	12-Feb-98	46	0			**Min**	33	
8	09-Feb-98	13-Feb-98	45	0			**Max**	70	
9	10-Feb-98	14-Feb-98	48	0					
10	11-Feb-98	15-Feb-98	50	0		**Shortage per cycle**			
11	12-Feb-98	16-Feb-98	49	0			**Average**	0.258	
12	13-Feb-98	17-Feb-98	50	0					
13	14-Feb-98	18-Feb-98	46	0			**Demand**	**?**	VCRs/year
14	15-Feb-98	19-Feb-98	41	0			**Cycles**	**?**	/year
15	16-Feb-98	20-Feb-98	43	0			**Shortage**	**?**	VCRs/year
16	17-Feb-98	21-Feb-98	46	0			**Fill rate**	**?**	

	A	B	C	D	E	F	G	H	I
363	30-Jan-99	03-Feb-99	51	0					
364	31-Jan-99	04-Feb-99	47	0					

Cell:	Formula:	Propagated to:
A4	=IF('daily demand'!A4+Leadtime-1<='daily demand'!$A$368,'daily demand'!A4,"") (Note: 'Leadtime' is a name for cell H2)	A5:A368
B4	=IF(A4="","",A4+Leadtime-1)	B5:B368
C4	=IF(B4="","",SUM(INDEX(DemandSample,ROW()-ROW($C$3)):INDEX(DemandSample,ROW()-ROW($C$3)+Leadtime-1))) (Note: 'DemandSample' is a name for the range B4:B368 in the 'daily demand' worksheet. This formula adds up the demand from the date in cell A4 to the date in cell B4. Concentrate on understanding what this complex formula does, as opposed to how it does it.)	C5:C368
D4	=IF(C4="","",IF(C4>reorder_point,C4-reorder_point,0)) (Note: 'reorder_point is a name for cell H1)	D5:D368
H5	=average(C4:C368)	
H6	=stdev(C4:C368)	
H7	=min(C4:C368)	
H8	=max(C4:C368)	
H11	=average(D4:D368)	

Remember: The **leadtime** is 5 days. The **length of a cycle** (time between orders) is 8 days.

The Reorder Point (ROP) is used to control the level of customer service:

Higher ROP

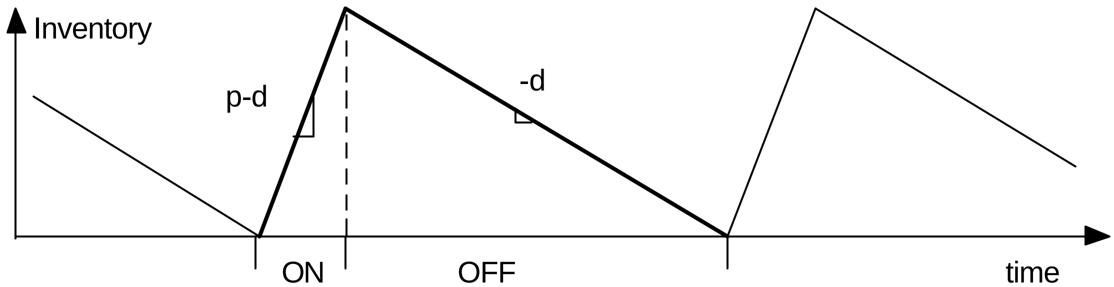
⇒less likely to run out of stock before next order arrives

⇒more likely able to satisfy all customer demand

but – higher average inventory level

Production Lot Size (PLS) Model

Difference between **EOQ** and **PLS**: the inventory is built gradually (produced) in the PLS



Q = number of items produced per production run

p = production rate (items per unit time)

d = demand rate (must be same units as p but not D)

$$Q^* = \sqrt{\frac{2DS}{H}\left(\frac{p}{p-d}\right)}$$

Note that as $p \to \infty$, $\left(\frac{p}{p-d}\right) \to$,

and $p = \infty$ corresponds to

Considering the optimal lot size formula, how can a company move towards JIT?

Formulas

Cycle length = T = Q/d (ON + OFF periods)

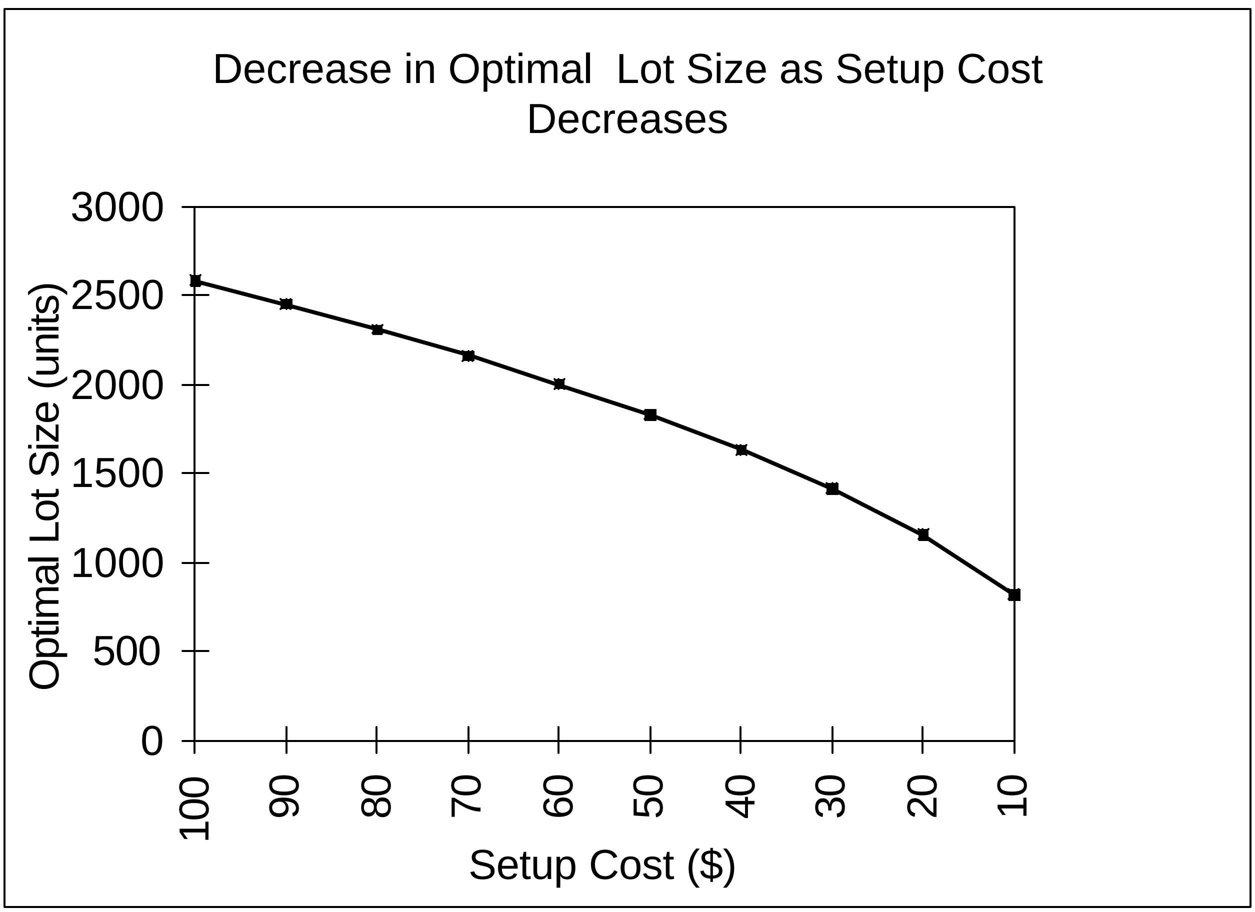
The length of the production ON period: $T_{ON} = Q/p$

Maximum inventory: $I_{max} = Q(p\text{-}d)/p$

Average inventory: $I_{avg} = I_{max}/2$

Total cost: $TC(Q) = \dfrac{SD}{Q} + \dfrac{HQ(p-d)}{2p}$

	A	B	C	D	E	F	G
1	**Optimal Lot Sizing Problem**				Note: assume 250 days per year		
2							
3	daily usage rate		40	d	=SQRT((2*C4*C6/C7)*C5/(C5-C3))		
4	annual demand		10,000	D			
5	daily production rate		100	p			
6	setup cost ($/setup)		50	S		Optimal	
7	holding cost ($/unit-yr)		0.5	H		Lot Size:	1825.74
8							
9	**Setup**	**Optimal**	**Cycle**	**Production**	**Maximum**	**Number**	**Total**
10	**cost**	**Lot Size**	**Length**	**Period**	**Inventory**	**of Turns**	**Cost**
11	($/setup)	(units)	(days)	(days)	(units)	(per year)	($)
12	100	2581.99	64.55	25.82	1549.19	3.87	774.60
13	90	2449.49	61.24	24.49	1469.69	4.08	734.85
14	80	2309.40	57.74	23.09	1385.64	4.33	692.82
15	70	2160.25	54.01	21.60	1296.15	4.63	648.07
16	60	2000.00	50.00	20.00	1200.00	5.00	600.00
17	**50**	**1825.74**	**45.64**	**18.26**	**1095.45**	**5.48**	**547.72**
18	40	1632.99	40.82	16.33	979.80	6.12	489.90
19	30	1414.21	35.36	14.14	848.53	7.07	424.26
20	20	1154.70	28.87	11.55	692.82	8.66	346.41
21	10	816.50	20.41	8.16	489.90	12.25	244.95



The Cups Game

Definitions

Push system: every station produces as much as they can, all the time.

Pull system: a station can only produce when its downstream buffer (called Kanban) is empty.

Kanban: the buffer between two stations in a pull production system. The size of the Kanban determines how much inventory can be between two stations. The size of the Kanban is also called the transfer batch size.

Buffer: space to store inventory in. The inventory could consist of raw materials, partially finished product or finished product.

MLT = Manufacturing Lead Time: the time from when work begins on an order until the order is ready to ship.

WIP = Work In Process: inventory of partially finished products.

Rework: the work needed to fix defective product.

Throughput rate: the rate at which a production system produces product – for example, 10 units per minute.

Push/Pull Comparison

	Push	Pull-4
Space needed		
Throughput		
MLT		
WIP		
Rework		

BigBluePills, Inc.

BigBluePills, Inc., provides and sells expensive drug treatments. BigBluePills does not produce the required drugs, but orders them from a subcontractor. The drugs are perishable -- they last for only 3 months. BigBluePills places an order for the drugs once every 3 months, and pays $400 for the drugs needed for one treatment. If the number of patients requiring the treatment during a 3 month period exceeds the quantity of drugs BigBluePills has available, then a rush order is placed at a cost of $1000 (because of higher production costs and express shipping). Drugs that are left over at the end of a 3 month period must be discarded. BigBluePills charges $650 for each drug treatment (Regardless of whether the drugs had to be rush ordered).

The number of patients requiring the treatment has been stable, but highly variable, in the last 5 years. Demand data for these 5 years is attached.

Can you help BigBluePills decide how large an order to place each quarter?

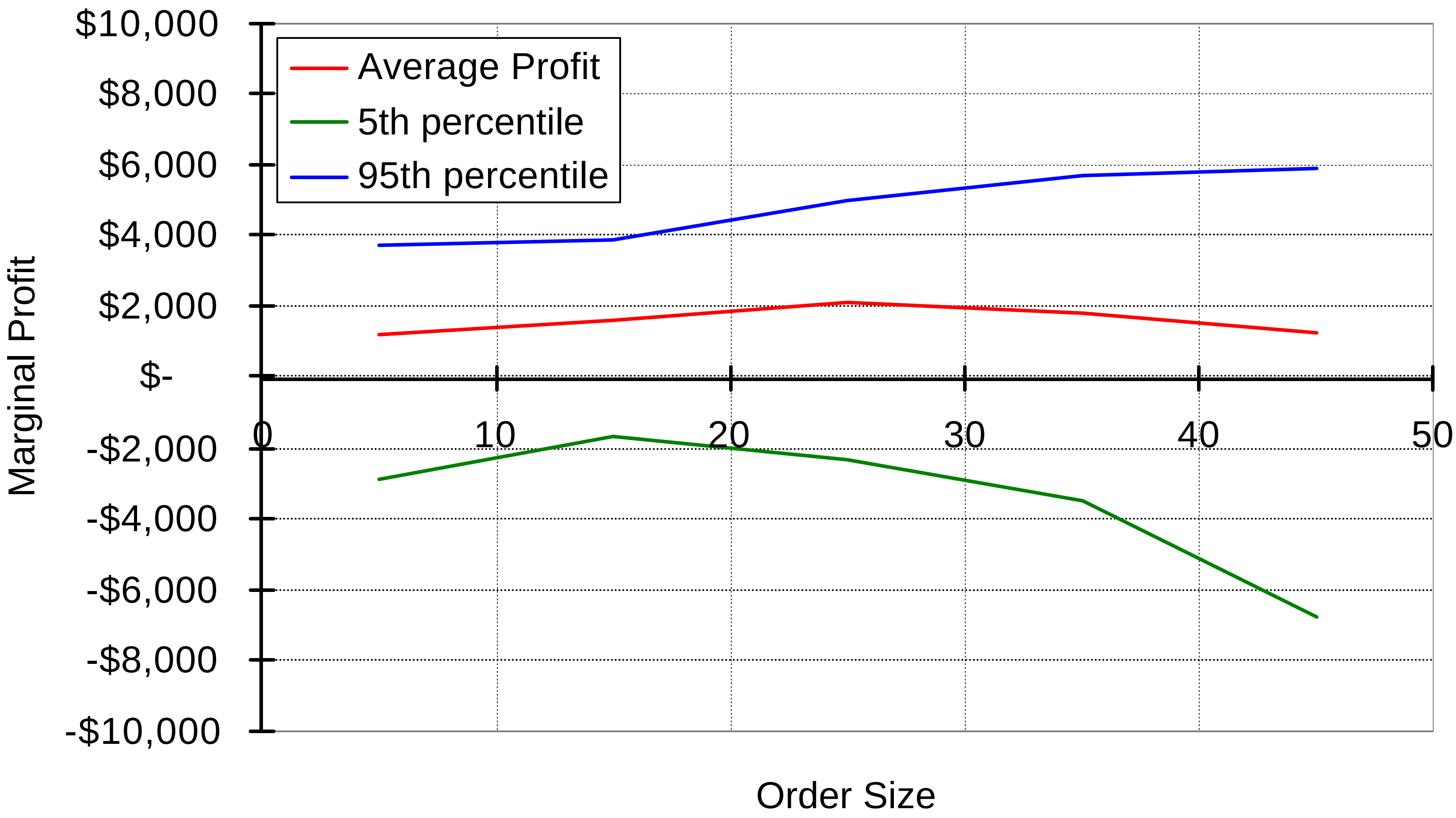
Demand Data

Year	Quarter	Demand
1992	Q1	10
	Q2	26
	Q3	14
	Q4	9
1993	Q1	22
	Q2	20
	Q3	22
	Q4	23
1994	Q1	5
	Q2	21
	Q3	21
	Q4	13
1995	Q1	21
	Q2	18
	Q3	10
	Q4	17
1996	Q1	34
	Q2	19
	Q3	20
	Q4	15

Example

Regular cost	$ 400
Rush cost	$ 1,000
Selling price	$ 650
Order size	10
Demand	19
Revenue	$ 12,350
Regular cost	$ 4,000
Rush orders needed	9
Rush order cost	$ 9,000
Marginal profit	-$650

Profit simulation



PROJECT MANAGEMENT

Introduction

Project: A one-time set of activities (tasks) with a clearly defined beginning and end.

Examples of projects:

- Building a highway,
- Writing software,
- Opening a new store,
- Organizing the Fringe Festival,
- Designing a new car,
- Putting man on the moon,
- Getting a B.Com.

Example of something that is not a project: Ongoing production or ongoing delivery of a service.

Every activity has an associated

- **duration** (could be uncertain)
  (might be possible to reduce, at extra cost)
- **resource requirement** (capital, labor, etc.)
- immediate **predecessor** activities

Aspects of Project Management

Before the project starts:

- *Creating the project*: What are the activities that need to be finished? What must come before what?
- Can the project be completed in time and within budget, given current manpower and other resources?
- If not, what needs to be done to make it possible?
- Who should work on what activity when?
- Which activities is it most important to monitor?
- How much uncertainty is there about when the project will be finished?

During the project:

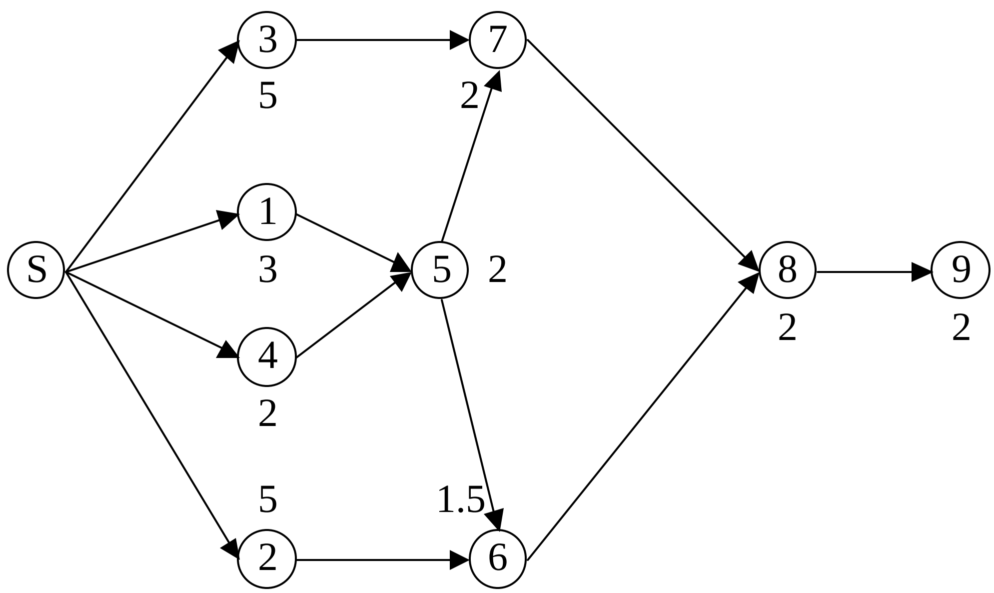
- Is the project on schedule?
- If not, what needs to be done to get it back on schedule?

Example: Relocating a Business

Linda Madison owns Creations, a business that provides hair and nail care services in a small college town. Recently, Linda has decided to expand her business to include tanning and massage services for her clients. In order to accommodate these new services and the additional clients they are expected to attract, Linda is relocating her business to a larger facility. However, the new location will require some renovation before she can relocate there. Linda has identified the following activities that must be performed before she can open at her new location:

Activity	*Description*	*Duration (days)*	*Immediate Predecessors*
1	Install new plumbing	3	-
2	Order and receive furniture	5	-
3	Order and receive flooring	5	-
4	Construct partitions	2	-
5	Paint and wallpaper	2	1, 4
6	Install furniture	1.5	5, 2
7	Install flooring	2	5, 3
8	Move inventory and records	2	6, 7
9	Clean old shop	2	8

We begin by constructing a **project network**:



To answer the question “how long will it take to finish the project?” we use...

The Critical Path Method (CPM)

The **critical path** for the project is the **longest path** through the project network.

- Critical path for example: _____________
- Duration of critical path:___________
- Activities with slack:____________

Duration of critical path = time needed to complete project

This is why activities on the critical path are important: if they are delayed, the whole project will be delayed.

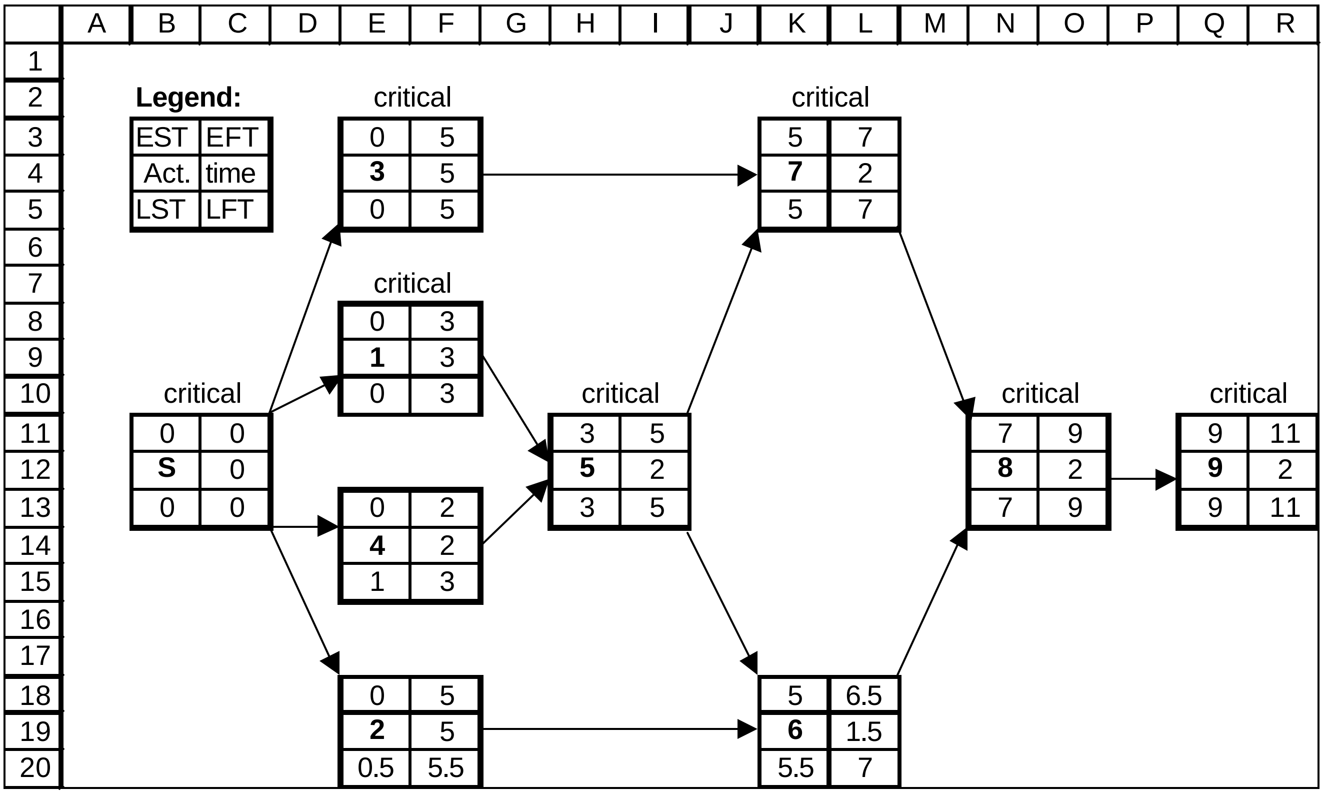
It would take a very long time to enumerate all possible paths in order to find the critical one for a realistic project network. Fortunately, a simpler method is available: The **critical path method** (CPM). CPM computes the following quantities for every activity:

EST = earliest start time	EFT = earliest finish time
LST = latest start time	LFT = latest finish time

EST = max(EFT of predecessors); EFT = EST + dur.

LFT = min(LST of successors); LST = LFT - dur.

We will use EXCEL to find the critical path through the example network:



⮰ Representative Formulas ⮵

Cell	*Formula*
E3	
F3	
H11	
O13	
N13	
I13	

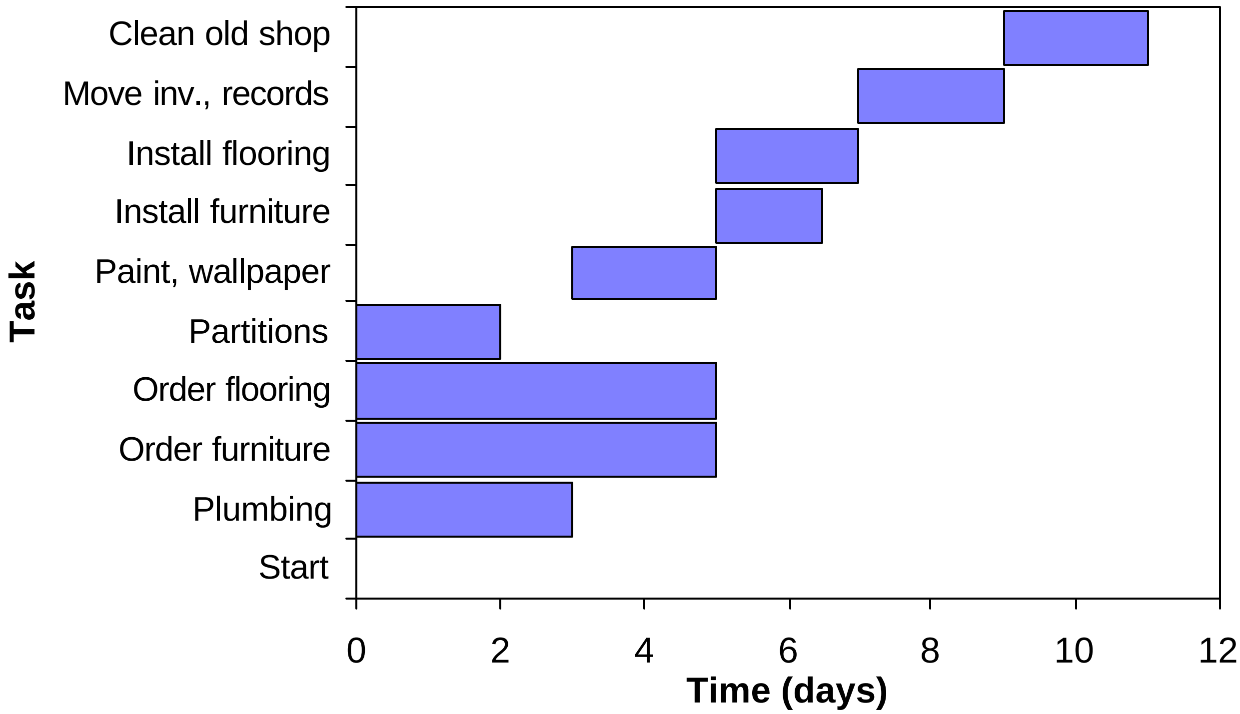
Another way of doing the same thing:

	A	B	C	D	E	F	G	H	I
1	**Activity**	**Description**	**Duration**	**EST**	**EFT**	**LST**	**LFT**	**Slack**	
2	S	Start	**0**	**0**	**0**	**0**	**0**	**0**	**
3	1	Plumbing	**3**	**0**	**3**	**0**	**3**	**0**	**
4	2	Order furniture	**5**	**0**	**5**	**0.5**	**5.5**	**0.5**	
5	3	Order flooring	**5**	**0**	**5**	**0**	**5**	**0**	**
6	4	Partitions	**2**	**0**	**2**	**1**	**3**	**1**	
7	5	Paint, wallpaper	**2**	**3**	**5**	**3**	**5**	**0**	**
8	6	Install furniture	**1.5**	**5**	**6.5**	**5.5**	**7**	**0.5**	
9	7	Install flooring	**2**	**5**	**7**	**5**	**7**	**0**	**
10	8	Move inv., records	**2**	**7**	**9**	**7**	**9**	**0**	**
11	9	Clean old shop	**2**	**9**	**11**	**9**	**11**	**0**	**
12									
13		Note: "**" denotes critical activities.							

Representative Formulas

Cell	*Formula*
D9	
E9	
G11	
F5	
G5	
G2	
H6	
I2	

An advantage of this setup is that one can easily generate a **Gantt chart** of the project. This Gantt chart assumes all activities begin at the earliest time possible.



A Gantt chart is a visual display of activities over time. Useful for display, but not for planning.

How to plot a Gantt Chart **(refer to previous spreadsheet)**

Excel 97/2000 instructions:

1. Highlight the region B1:D11.
2. Invoke the chart wizard. Select a bar chart, with sub-option "Stacked Bars". Click "Next" several times and then "Finish".
3. Single-click on one of the bars that correspond to "Duration". Choose "Selected Data Series ..." from the format menu. On the "Series Order" tab, move "Duration" down so that it comes after "EST". On the "Options" tab, set the gap width to 50 (or whatever looks good to you). On the "Patterns" tabs, choose "None" for both area and border.

Microsoft Project

Using Excel for simple project planning is useful, but for large and complex projects we should use project-planning software. In this course, we will use Microsoft Project 98. Since Project is specifically designed for project planning, it takes care of many of the details that we had to worry about with Excel, while at the same time providing more functionality and greater capabilities. Project 98 has millions of users worldwide, and is becoming the de facto standard in project planning software.

Scheduling in Project

We will begin by using Project to schedule the same renovation project that we did in Excel.

1. Open Microsoft Project 98. A new project should be started by default.

2. In the 'Task Name' column, enter the first task "Plumbing." Note that a "Start" task is not needed in Project. Press enter. You should see this on the screen:

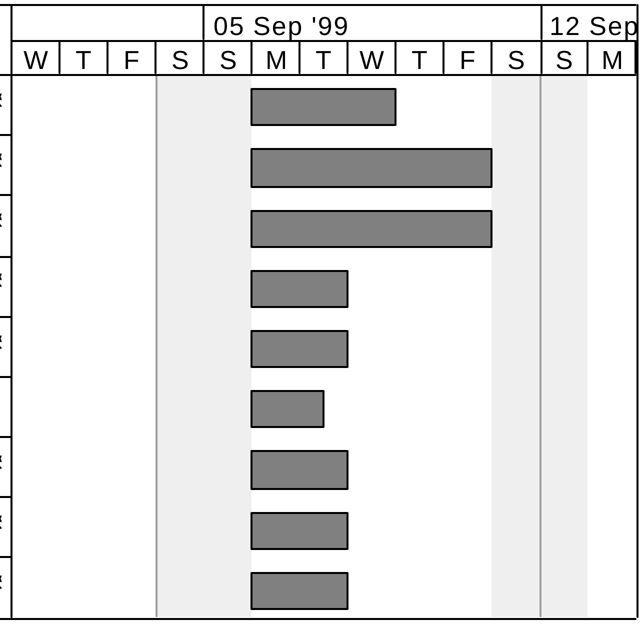
ID		Task Name	Duration	29 Aug '99							05 Sep '99		
				S	M	T	W	T	F	S	S	M	T
1		Plumbing	1 day										

3. Repeat step 2 for the remaining tasks, filling in all of the tasks in this project

4. Now we will go back and edit each task's duration. Click on the duration cell of the "Plumbing" task and enter its duration (10 days), and then press 'Enter.' Project moves your cursor to the duration corresponding to the next task.
5. Repeat step 4 for the remaining tasks.

Now, your project should like this:

ID		Task Name	Duration
1		Plumbing	3 days
2		Order Furniture	5 days
3		Order Flooring	5 days
4		Construct Partitions	2 days
5		Paint, Wallpaper	2 days
6		Install Furniture	1.5 day
7		Install Flooring	2 days
8		Move inventory & records	2 days
9		Clean old shop	2 days



Dependent Tasks

Now we need to indicate which tasks are dependent on the others. This is called **linking tasks** in Project. When linking tasks, we must consider both the tasks to be linked, and the order that they are to be linked. By default, Project links tasks in “Finish to Start” order. This means that when you indicate two or more tasks to be linked, Project takes the first task as the task that needs to be finished before the second task can be started. To link the first set of tasks in our project, do the following:

1. Click on the “Order Furniture” item in the ‘Tasks’ column.
2. Hold down the ‘Control’ key, and click on the “Install Furniture” item in the ‘Tasks’ column. Both items should now be selected.
3. In the Project toolbar, click on the  icon. The bar representing the “Install Furniture” task should move to show it is dependent on the “Order Furniture” task.

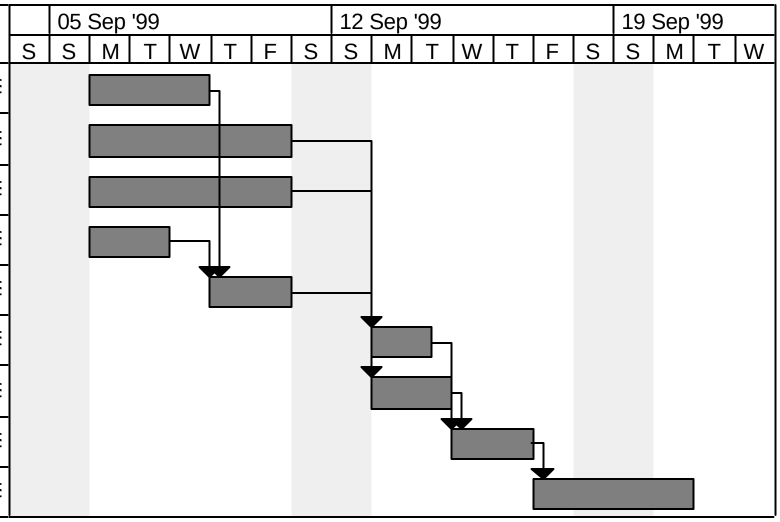
Repeat this process for the remaining dependent tasks.

As you do this, you will see that Project calculates the ESTs automatically (watch how the bars move). Also notice that Project automatically takes weekends into account.

Viewing the Critical Path

To see the critical path, right-click somewhere on the Gantt chart. Choose “Gantt Chart Wizard.” Click “Next,” select “Critical Path,” click “Finish,” click “Format It,” and finally “Exit.” Now your project should look like this:

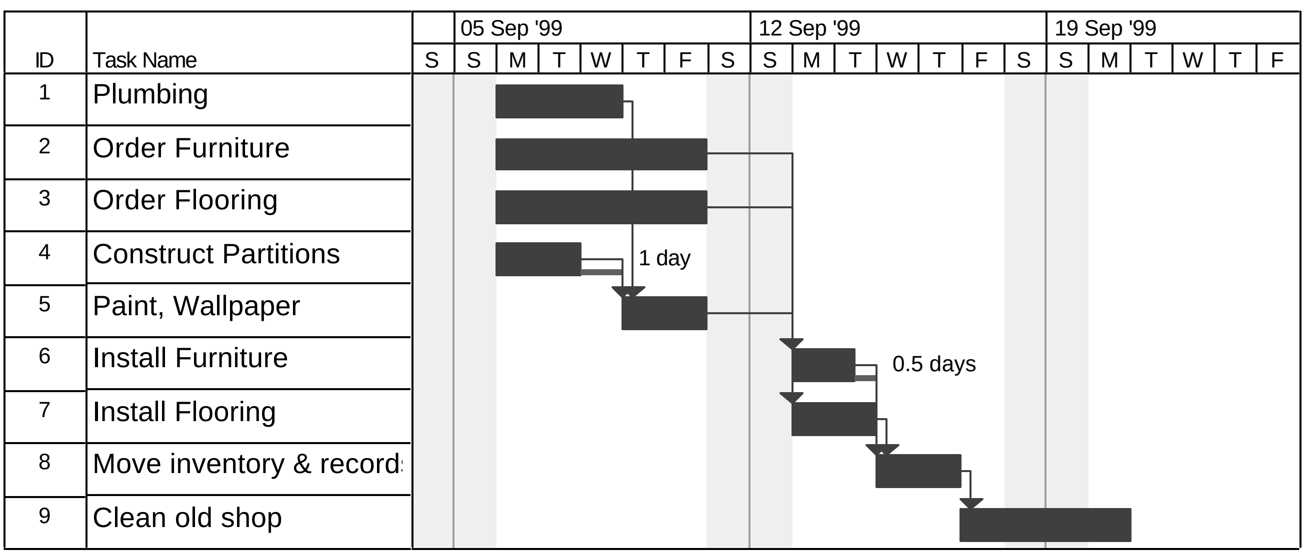
ID		Task Name	Duration
1		Plumbing	3 days
2		Order Furniture	5 days
3		Order Flooring	5 days
4		Construct Partitions	2 days
5		Paint, Wallpaper	2 days
6		Install Furniture	1.5 days
7		Install Flooring	2 days
8		Move inventory & record	2 days
9		Clean old shop	2 days



Viewing Slack

Slack, or float, is the amount of time a task can be delayed before it affects another task's dates or the project finish date. **Free slack** is the amount of time a task can slip before it delays another task. **Total slack** is the amount of time a task can slip before it delays the project finish date. To view the slack in our current project, do the following:

1. Under the 'View' menu heading, click on 'More Views…'. A dialog box should open, presenting you with more views of your project.
2. Select "Detail Gantt" and click on 'Apply. The dialog box should close and the Gantt chart should change, showing thick green lines indicating the free slack.



We see that "construct partitions" has free slack of 1 days and "install furniture has a free slack of 0.5 days. What about the "order furniture" task? According to Excel, it also had a slack of 0.5 days.

Project Cash Flows

Linda has estimated the following costs for each activity:

Activity	Cost
Plumbing	$4,000.00
Order Furniture	$5,000.00
Order Flooring	$3,000.00
Construct Partitions	$2,000.00
Paint, Wallpaper	$1,500.00
Install Furniture	$1,000.00
Install Flooring	$900.00
Move inventory & records	$500.00
Clean old shop	$200.00

These costs are incurred at a constant rate per day throughout the duration of each activity.

How much money will Linda need to spend each day?

(see the workbook CashFlows.xls – available from course web).

Project Monitoring

Linda's relocation project started on November 17th. It is now November 25th, and Linda has just taken stock of which activities are finished:

Activity	**% complete**
Plumbing	100%
Order Furniture	70%
Order Flooring	100%
Construct Partitions	100%
Paint, Wallpaper	100%
Install Furniture	0%
Install Flooring	10%
Move inventory & records	100%
Clean old shop	100%

Entering this information in MS Project (see the file ProjectPlanning.mpp, available from course web):

1. Project → Project Information to set start date.
2. Choose 'Tracking Gantt' view.
3. Choose 'Tracking' table.
4. Fill in the '% Comp.' Column. Notice how the critical path changes. Notice the vertical line representing today's date.

Workload Smoothing Heuristic

Question: What is the minimum level of resources I need to complete the project?

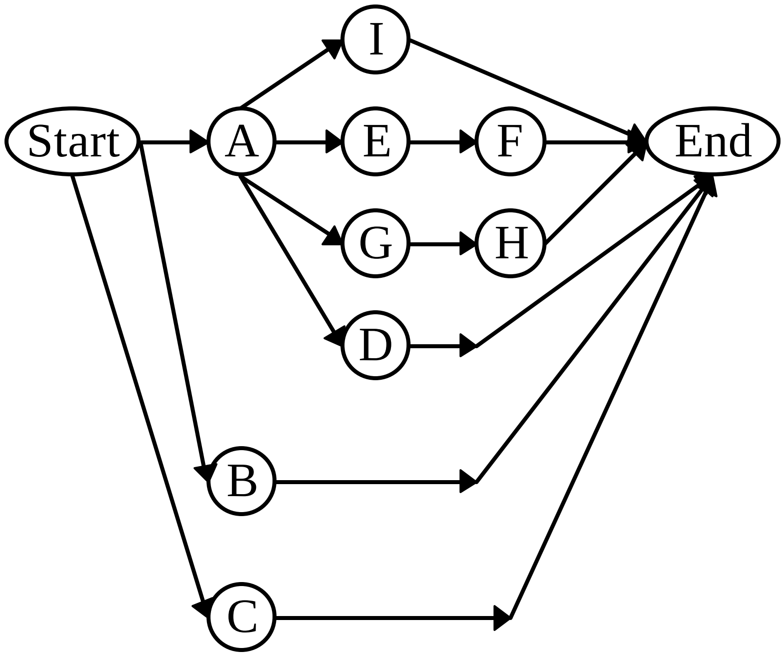
Resources could be labor, capital, etc.

The workload smoothing heuristic answers this question. “Heuristic” means the answer is not guaranteed to be the best possible answer, but is hopefully pretty good.

Example:

Activity	*Duration (weeks)*	*Predecessors*	*# of people required per week*
A	3	-	6
B	2	-	3
C	1	-	3
D	1	A	3
E	2	A	6
F	4	E	5
G	1	A	3
H	2	G	4
I	2	A	3

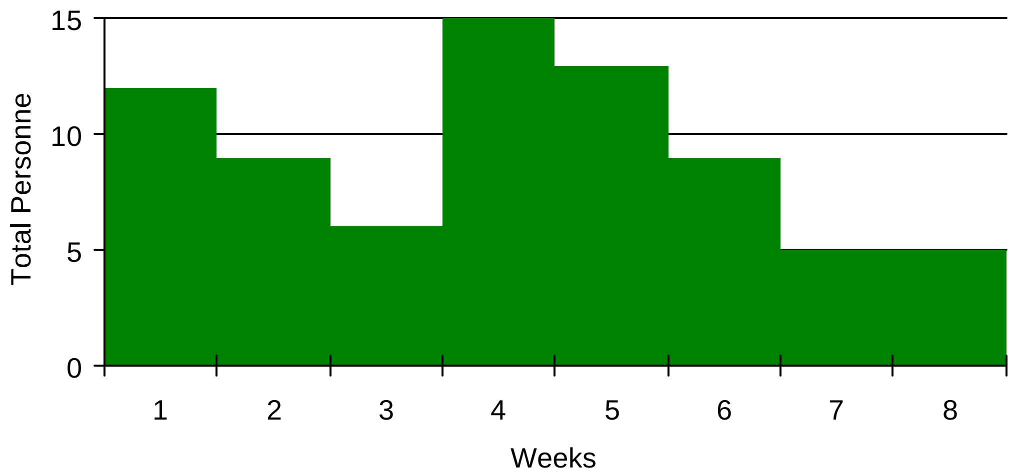
Project network:



Schedule where all activities begin at their EST's:

Week	1	2	3	4	5	6	7	8	9
	A			E		F			
	6	6	6	6	6	5	5	5	5
	B								
	3	3	Slack						
	C								
	3	Slack							
				D					
				3	Slack				
				G	H				
				3	4	4	Slack		
				I					
				3	3	Slack			
Total Personnel	12	9	6	15	13	9	5	5	5
New limit:	14	14	14	14	14	14	14	14	14

Workload profile:



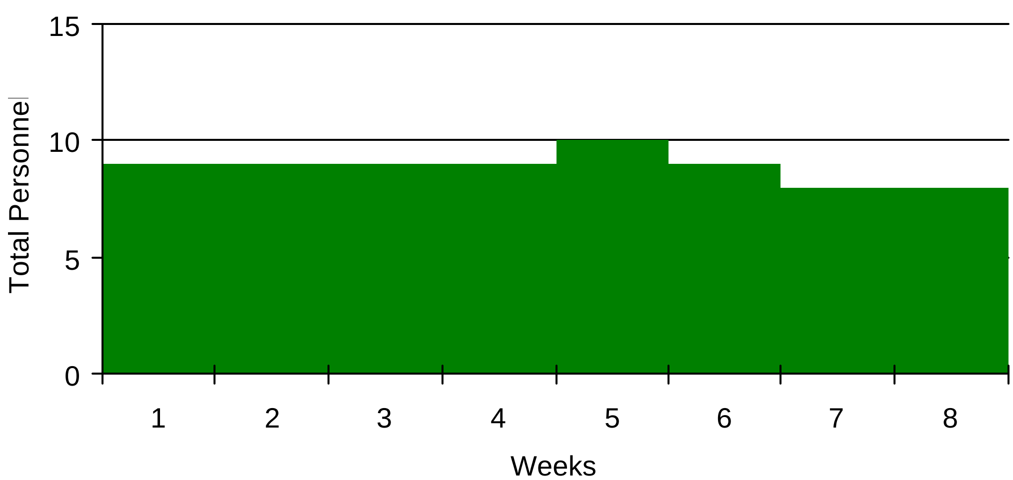
Workload Smoothing Heuristic:

1. Find the maximum required resources in the proposed schedule, say M.
2. Attempt to lower the resource usage, in every week, down to at most M-1. The schedule revision is performed systematically, as follows:
3. Find the first week where resource usage is greater than M-1. Consider the activities being worked on during that week and find the one with the most slack. Move it forward (into the future) as little as possible until the resource usage drops down to or below M-1. Do not move the activity so far that the completion of the entire project is delayed.
4. If you were able to reduce the maximum resource usage, go back to step 1. Otherwise, stop.

Schedule after workload smoothing heuristic has been applied:

Week	1	2	3	4	5	6	7	8	9
	A			E		F			
	6	6	6	6	6	5	5	5	5
	B								
	3	3	Slack						
			C						
			3	Slack					
									D
									3
				G	H				
				3	4	4	Slack		
							I		
							3	3	Slack
Total Personnel	9	9	9	9	10	9	8	8	8
New limit:	9	9	9	9	9	9	9	9	9

Workload profile:



“Optimal” schedule:

Week	1	2	3	4	5	6	7	8	9
	A			E		F			
	6	6	6	6	6	5	5	5	5
	B								
	3	3	Slack						
			C						
			3	Slack					
				D					
				3	Slack				
					G	H			
					3	4	4	Slack	
								I	
								3	3
Total Personnel	9	9	9	9	9	9	9	8	8
New limit:	8	8	8	8	8	8	8	8	8

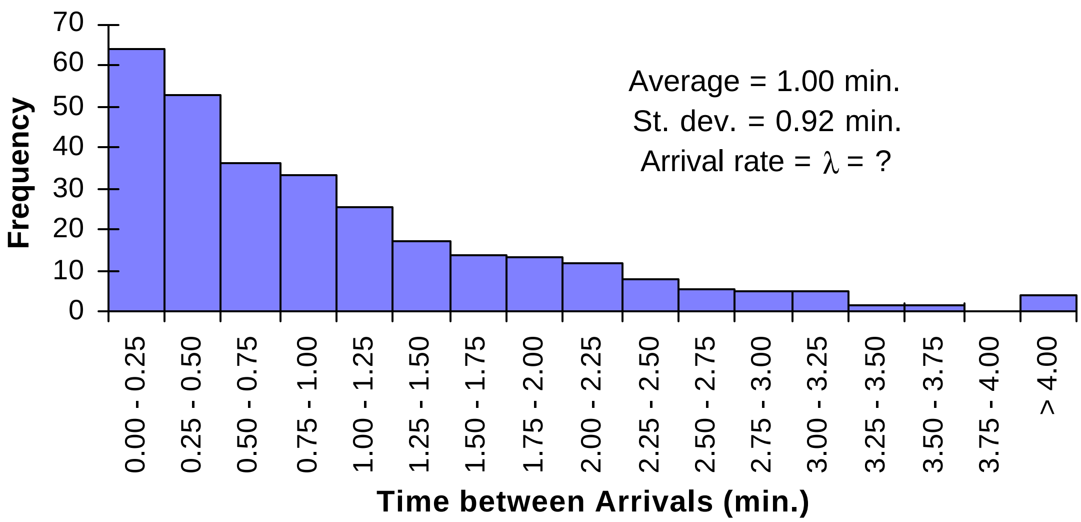
MANAGING CONGESTION[1]

Asgard Bank's ATM

-- An Example of a Congested System

Frigg, the operations manager of Asgard Bank, Inc. (AB) is trying to improve levels of service at the bank's automatic teller machines (ATMs). To try to get a handle on the problem, Frigg is looking at some statistics for an ATM where customers have complained repeatedly of long lineups during the hour from noon to 1 PM.

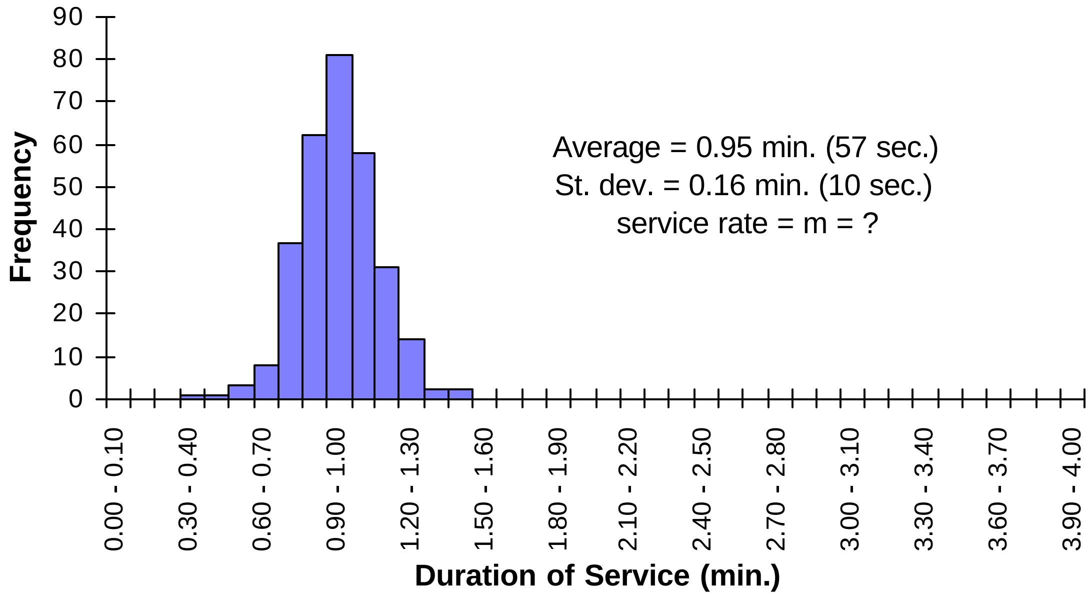
First, she looks at the times between successive customer arrivals to the ATM. Her recently-hired assistant, Loki, has spent his last five lunch hours watching customers arrive to the ATM and timing their arrivals. Based on his analysis, the average time between arrivals during this peak period is 1 minute, the standard deviation of the time between arrivals is 0.92 minutes, and a histogram of the times between arrivals looks as follows:



Next, she looks at data that another of her assistants, Baldur, has provided her with: the durations of service encounters, from the time the customer enters his card until the card is returned. This data is recorded automatically by the ATM. According

[1] The tools we are going to talk about are usually called "Queueing Theory" or "Waiting Line Analysis," but this terminology can be misleading, since the goal of the modeling is usually to discover how waiting can be *avoided*.

to this data, the average duration of service is 57 seconds, with a standard deviation of 10 seconds. A histogram of 300 service durations looks as follows:



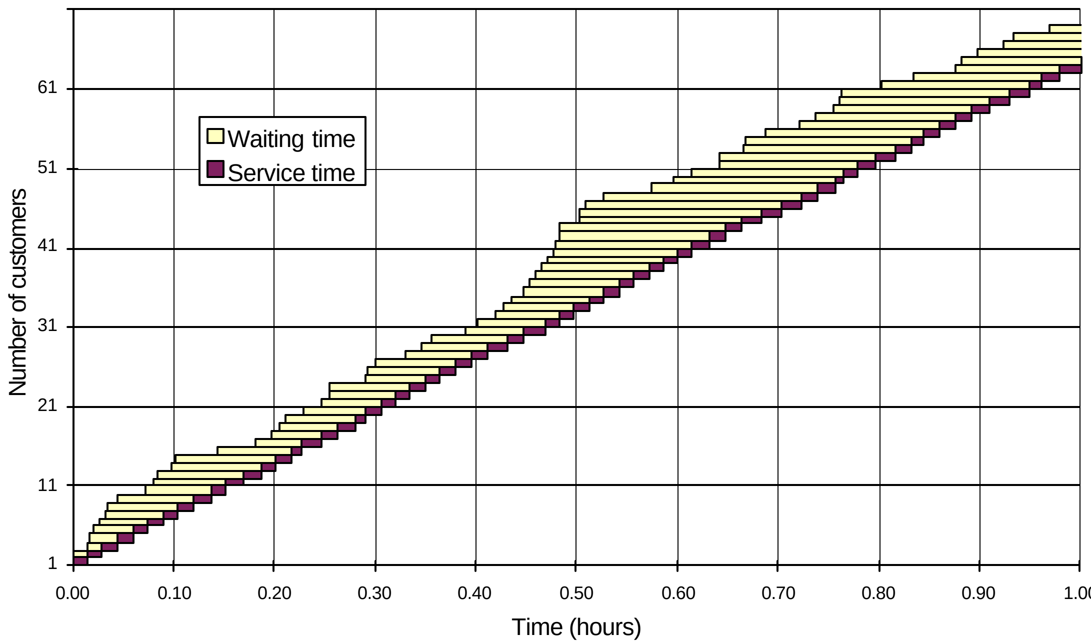
Frigg is puzzled by the numbers. The average time between customer arrivals is 1 minute. This means that, on average, 60 customers arrive during a lunch hour. The average time needed to service a customer is 57 seconds, so 60 customers can be serviced in (60)(57) = 3420 seconds = 57 minutes, which is less than 1 hour. So the ATM should be able to handle the load during a typical lunch hour.

And yet the customers complain of long lines in front of the ATM during lunch hour. How can this be?

We will try to help Frigg understand why the customers are complaining by building a simulation model of the customers that wait in front of the ATM. Based on the histograms, we will assume that the times between customer arrivals come from an exponential distribution with a mean of 1 minute and durations of service encounters come from a normal distribution with a mean of 0.95 minutes and a standard deviation of 0.16 minutes.

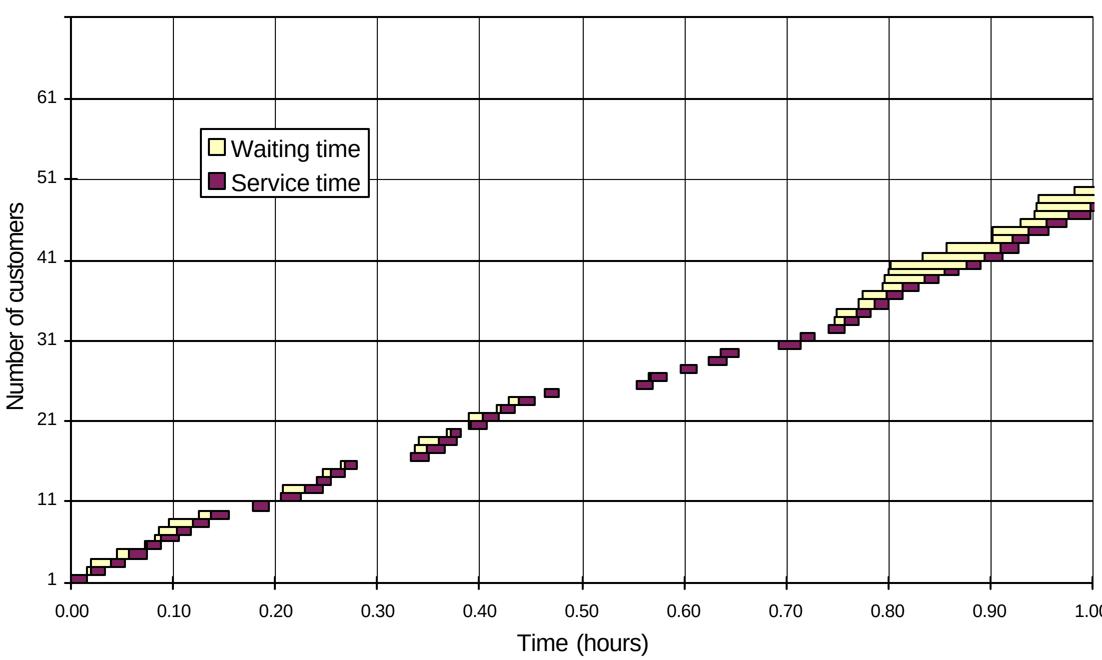
We will not tell you how the simulation is constructed, but we will show you the results of simulating a few lunch hours.

Lunch hour 1:



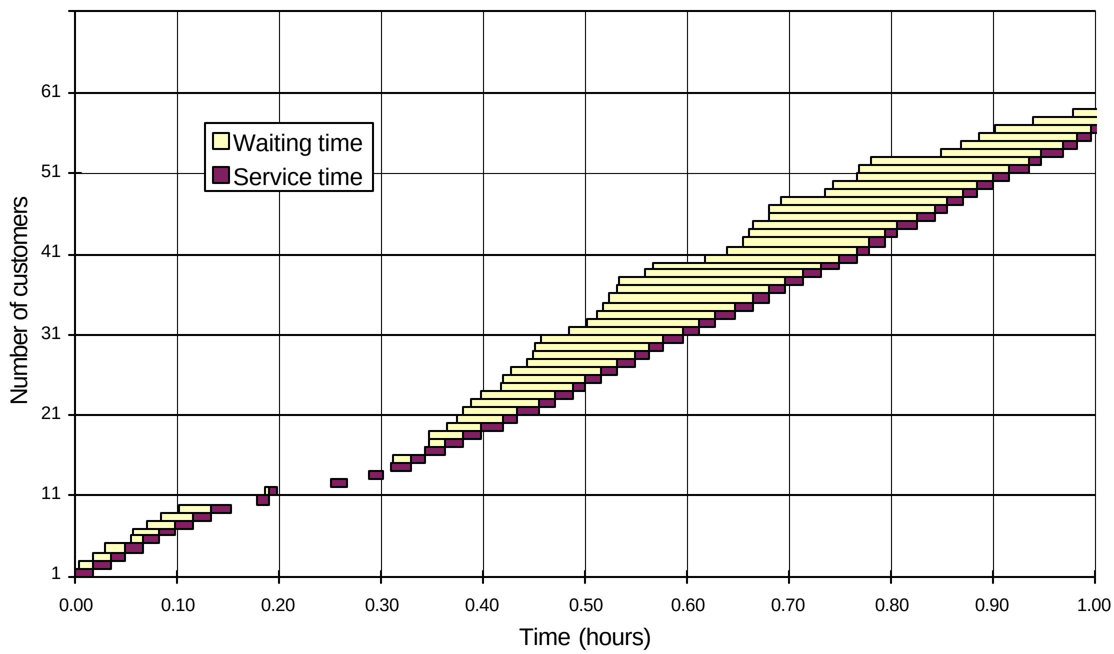
There were people waiting throughout most of this lunch hour. This happened because the number of customers that arrived (70) was higher than average. This is not that unusual; one can expect 70 or more customers to arrive during lunch hour every eighth day or so.

Lunch hour 2:



This was a pretty good lunch-hour, service-wise, mainly because only 50 customers arrived. Again, this is not that uncommon; one can expect 50 or fewer customers about every sixth day.

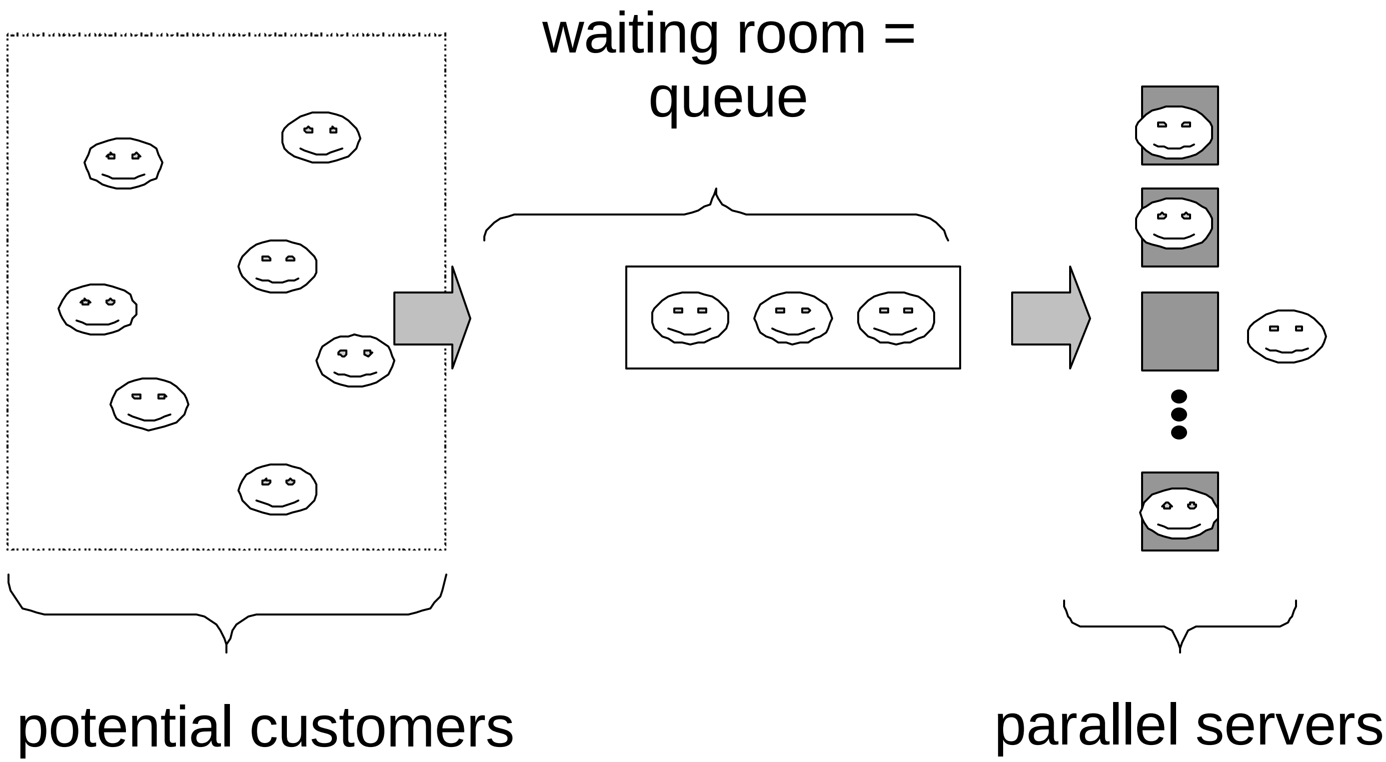
Lunch hour 3:



The number of customers that arrived during this lunch hour was close to average (60). Still, the line started to build up and there were about 6 people waiting at 12:30 PM. Why did this happen? The ATM should be able to serve 63 customers per hour. The problem is that most of the customers arrived during the second half of the lunch hour. In fact, the ATM was idle for a 5 minute period early in the lunch hour. So the capacity was there, but the customers weren't. Unfortunately, the capacity cannot be stored; if it's not used it's gone.

Frigg's lesson: For a service where customers arrive randomly, it is not a good idea to operate the system close to its capacity.

Anatomy of a Congested System



We will analyze three types of congested systems:

Type	Number of potential customers	Number that can wait	Number of servers	Inter-arrival time distribution	Service time distribution
M/M/s	∞	∞	s	exponential	exponential
M/M/s/s+C	∞	C	s	exponential	exponential
Finite population	finite	∞	s	exponential	exponential
M/G/1	∞	∞	1	exponential	arbitrary

Analyzing a congested system

System Description

- μ (mu) =
- λ (lambda) =
- s =
- C =
- M =
- σ_S (sigma sub S) =

Model of the System

- Available formulas (queueing template, QTP)
- Simulation

Measures of Quality of Service

- Wq =
- W =
- Lq =
- L =
- SL =
- PrBalk =
- PrWait =

Measures important to Servers

- ρ (rho) =

Template for Waiting Line Analysis

The **Template for Waiting Line Analysis** is a workbook ("template.xls" -- we will make it available to you) that can be used to calculate performance measures for various types of congested systems.

For the Asgard Bank example, we need to provide the queueing calculator with the following numbers:

λ = arrival rate = 60 per hour

$1/\mu$ = average service duration = 57/3600 hours

σ = standard deviation of service durations = 10/3600 hours

We enter these numbers on the "M/G/1" sheet of the template.

M/G/1 Queueing Calculations

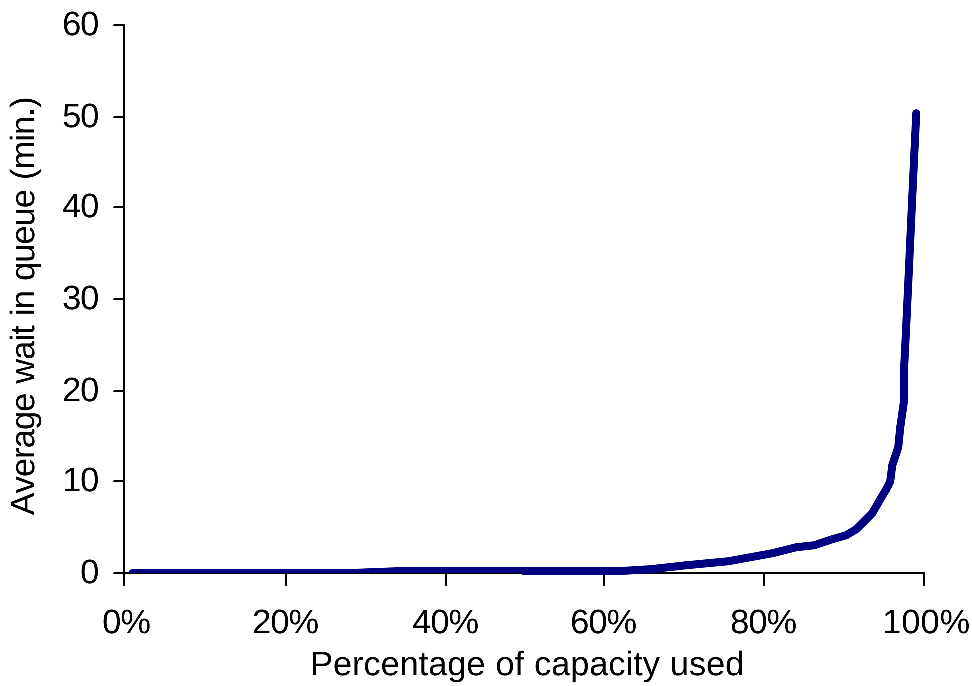
Basic Parameters		
Arrival Rate	**60**	per hour
Average service time	**0.015833**	hours
Stdev. Service time	**0.002778**	hours
Service rate (calculated)	**63.15789**	per hour
Time Unit	**hour**	

Basic Performance Measures		
Utilization	**95%**	
P(0), probability that the system is empty	**5%**	
Lq, expected number in queue	**9.3028**	
L, expected number in system	**10.2528**	
Wq, expected time in queue	**0.1550**	hours
W, expected total time in system	**0.1709**	hours

From this we learn the following:

- The ATM is busy 95% of the time.
- On average, there are 9.3 people waiting.
- On average, there are 10.25 people in the system (waiting, or using the ATM).
- Customers wait 0.155 hours = 9.3 minutes on average.

We can use the queueing calculator to vary the arrival rate from 0 per hour to 63 per hour. This corresponds to varying the server utilization from 0% to 100%. This is what happens to the average waiting time in the system:



This graph reinforces Frigg's lesson. One way to describe what the graph is saying is: As the **unused capacity** of the system decreases, the customer waiting times (and queue lengths) become very long. In fact, "unused capacity" is a misnomer; it is used to accommodate unpredictable surges in demand.

The Other Sheets of the Template

Template.xls has 4 worksheets:

- **M/M/s**: *M*emoryless arrival process, *M*emoryless service process, s servers (s can be 1, 2, 3, etc.).
  Example:

- **Finite queue length**: Same as M/M/s, except there is only room for a limited number of waiting customers. "Maximum number in queue" does *not* include customers being served.
  Example:

- **Finite population**: Same as M/M/s, except the population of customers that use the system is finite.
  Example:

- **M/G/1**: *M*emoryless arrival process, *G*eneral service process, 1 server.
  Example:

Input cells always have green letters in them.

Ride'n'Collide

The Ride'n'Collide bumper car amusement attraction has a problem with cars breaking down and needing repair, because of patrons taking the name of the attraction literally. Repair personnel can be hired at a rate of $10 per hour. On average, it takes a repair-person 30 minutes to repair a car. While a car is down, lost income is $50 per hour. There are 20 cars in total, and a car will function for 10 hours on average from the time it has been fixed until the next time it needs to be repaired. How many repair-people should be hired?

Solution

- Customers =
- Servers =
- Average number in system =
- Lost revenue per hour =
- Arrival rate =
- Service rate =
- Model to use:

	A	B	C	D	E	F	G
1	**Ride'n'Collide**						
2							
3	**Arrival rate**	**0.1**	per car per hour				
4	**Service rate**	**2**	per repairperson per hour				
5	**Number of cars**	**20**					
6	**Hourly wage**	**$10**	per hour				
7	**Lost income**	**$50**	per car that is down per hour				
8							
9	**# of repair-people**	1	2	3	4	5	
10							
11	**labor cost**	$10	$20	$30	$40	$50	per hour
12	**Avg. # of cars down**	1.89	0.61	0.51	0.50	0.50	
13	**lost income**	$94.45	$30.58	$25.72	$25.09	$25.01	per hour
14	**total cost**	$104.45	$50.58	$55.72	$65.09	$75.01	per hour

$\Rightarrow$ It is optimal to hire 2 repair-people.

The Cost of Randomness

A Call Center Example

Gayle Johnston, an employee of a mail order company, MEC, has two phone lines. She uses them to take calls from customers ordering products from the MEC catalog. The typical call lasts 4 minutes, and she gets 10 calls per hour but both of these numbers are averages; times vary from call to call. A consultant, hired to study the process, has told MEC that both the time to serve a call and the time between incoming calls closely follows an exponential distribution. If a second caller phones, Gayle can ask the incoming call to "hold please" and then return to the current caller. If a third caller calls before she finishes the current call, then that call gets a busy signal. MEC worries about losing customers because of this type of event. They want to know if it makes sense to add additional phone lines and/or operators. An average caller places orders leading to profits of $24.76 for MEC and the cost of another line (rental and connect time) would work out to $4.00 per hour. Gayle is paid $12.00 per hour.

a) What percentage of incoming calls will be 'lost'?
b) What fraction of the time is the operator busy answering calls?

M/M/s Finite Capacity Queueing Calculations

Basic Parameters		
Arrival Rate	10	per hour
Service Rate	15	per hour
Number of Servers	1	
Maximum queue length	1	
Time Unit	hour	

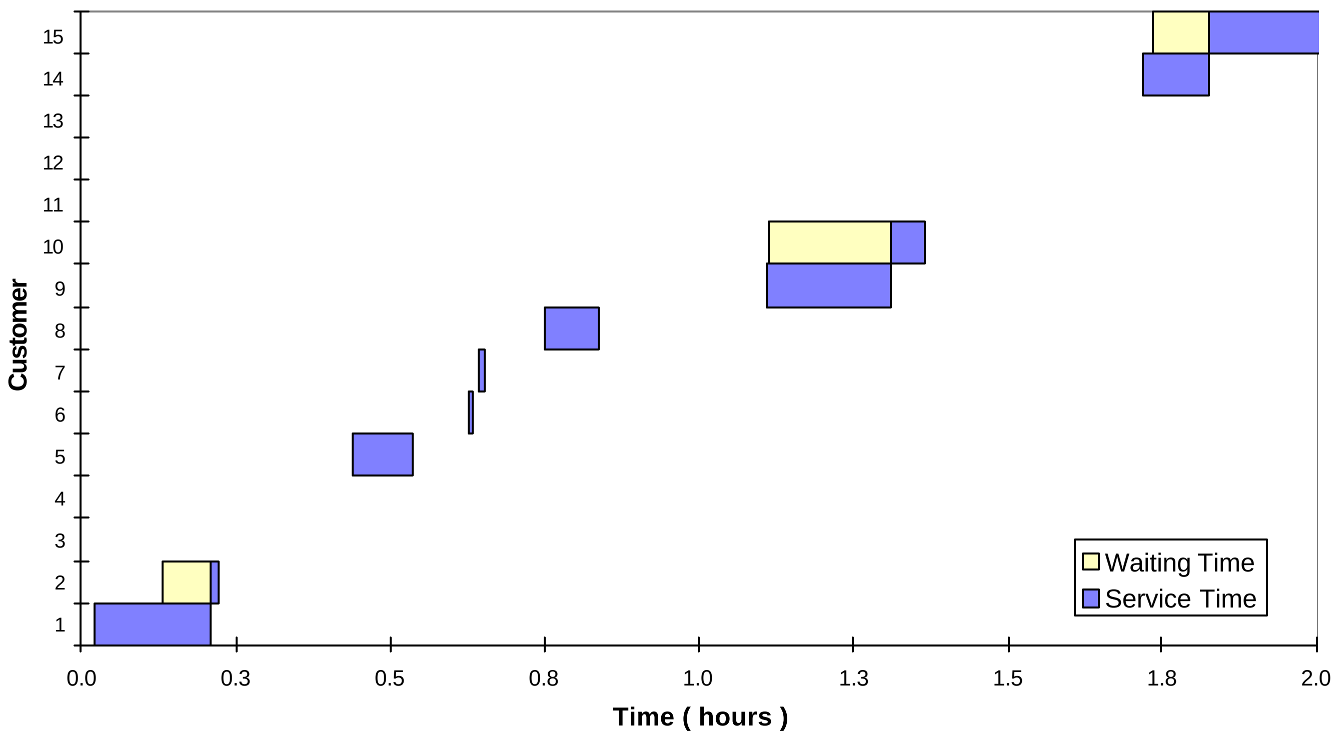
Basic Performance Measures		
Utilization	53%	
P(0), probability that the system is empty	47%	
Lq, expected number in queue	0.2105	
L, expected number in system	0.7368	
Wq, expected time in queue	0.0267	hours
W, expected total time in system	0.0933	hours
Probability that customer waits	53%	
Probability that a customer balks	21%	

State Probabilities	
Number in system	Probability
0	47%
1	32%
2	21%
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	

The following two figures are snapshots from a run of a **simulation model** (MMsLcap.xls - available from the course web). They depict a typical sequence of events in this mail-order system.

	A	B	C	D	E	F	G	H	I	J
1	**MEC Mail Order Staffing:**									
2		**Arrival rate of calls**	**10**							
3		**Service rate**	**15**							
4		**# of servers**	**1**							
5		**Queue Cap.**	**1**	(beyond those being served)						
6	**Customer #**	**Interarrival Time**	**Service Time**	**Arrival Time**	**Joins Queue?**	**Service Begins**	**Service Ends**	**Actual Serv. T.**	**Waiting Time**	**Time in System**
7	1	0.021	0.190	0.021	1	0.021	0.211	0.190	0.000	0.190
8	2	0.111	0.013	0.133	1	0.211	0.225	0.013	0.079	0.092
9	3	0.014	0.172	0.147	0	0.000	0.000	0.000	0.000	0.000
10	4	0.038	0.024	0.185	0	0.000	0.000	0.000	0.000	0.000
11	5	0.254	0.097	0.439	1	0.439	0.536	0.097	0.000	0.097

	A	B	C	D	E	F	G	H	I	J
206	200	0.123	0.054	18.524	1	18.524	18.577	0.054	0.000	0.054
207				Total:	159			Total:	3.593	13.653
208				Balk %	21%			Wq, W=	0.0226	0.08587



Optimization at MEC:

[Note: This problem is based on an application at L. L. Bean, the outdoor retailer in the U.S.A., where a queueing study which cost only $40,000 increased revenue by an estimated $10,000,000 per year. (Interfaces, Jan-Feb. 1991)]

We have just seen that a system with randomness in it (as is the case with most service systems) operates far less efficiently than we would expect using 'average' performance figures.

To deal with this randomness, MEC is considering hiring more operators to work alongside Gayle taking orders in parallel with her. The operators would work on the same set of lines taking the next available call waiting in the system. They also are considering adding extra 'hold' lines. Apart from the costs and revenues already mentioned, MEC is concerned with the time that customers have to wait while on hold – after all there is a limit to how much Barry Manilow anyone can take! MEC wants to keep this time below 1 minute on average. How many operators and extra phone lines should MEC have to maximize profit and still not lead to average waits on hold of over 1 minute?

	A	B	C	D	E	F	G	H	I
1	**Optimization of MEC**								
2									
3	**arrival rate**	**service rate**	**contr.**	**wage**	**line rental**				
4	**10**	**15**	**$24.76**	**$12**	**$4**				
5			/cust	/hour	/hour				
6									
7	**lines**	**agents**	**line cost**	**salary**	**% balking**	**# served**	**contr.**	**wait time**	**net contribution**
8	**2**	**2**	$16	$24	1.24%	9.88	$244.52	0.38	**$204.52**
9			/hour	/hour		/hour	/hour	min/cust.	/hour
10									
11					**agents**				
12		$204.52	1	2	3	4	5		
13	**lines**	1	$ 175.47	$ 202.26	$ 194.21	$ 179.43	$ 163.58		
14		2	$ 193.13	$ 204.52	$ 191.29	$ 175.57	$ 159.60		
15		3	$ 200.82	$ 202.58	$ 187.53	$ 171.60	$ 155.60		
16		4	$ 203.69	$ 199.26	$ 183.58	$ 167.60	$ 151.60		
17		5	$ 203.90	$ 195.49	$ 179.60	$ 163.60	$ 147.60		
18		6	$ 202.57	$ 191.56	$ 175.60	$ 159.60	$ 143.60		
19		7	$ 200.29	$ 187.59	$ 171.60	$ 155.60	$ 139.60		

Manufacturing Example

Jobs arrive for processing at a machine on a shop floor in a random fashion at an average rate of 1 per minute. The machine (and its human operator) can process an average of 1.2 jobs per minute but actual processing time is variable (exponentially distributed). It costs $1.20 per minute to operate the machine (whether it is processing or not). Management is considering replacing this machine with a faster one that can process an average of 1.8 jobs per minute (again this is just an average; actual times are subject to variation) but which is more expensive to operate ($2.00 per minute). Is this a good idea? Assume that there is lost revenue when jobs are being processed or waiting to be processed and this cost is $2.50 per minute.

M/M/s Queueing Calculations

Basic Parameters		
Arrival Rate	1	per hour
Service Rate	1.8	per hour
Number of Servers	1	
Time Unit	hour	

Basic Performance Measures		
Utilization	**56%**	
P(0), probability that the system is empty	**44%**	
Lq, expected number in queue	**0.6944**	
L, expected number in system	**1.2500**	
Wq, expected time in queue	**0.6944**	hours
W, expected total time in system	**1.2500**	hours
Probability that customer waits	**56%**	

State Probabilities	
Number in system	Probability
0	**44%**
1	**25%**
2	**14%**
3	**8%**
4	**4%**
5	**2%**
6	**1%**
7	**1%**
8	**0%**
9	**0%**
10	**0%**
11	**0%**

M/M/s Queueing Calculations

Basic Parameters		
Arrival Rate	1	per hour
Service Rate	1.2	per hour
Number of Servers	1	
Time Unit	hour	

Basic Performance Measures		
Utilization	83%	
P(0), probability that the system is empty	17%	
Lq, expected number in queue	4.1667	
L, expected number in system	5.0000	
Wq, expected time in queue	4.1667	hours
W, expected total time in system	5.0000	hours
Probability that customer waits	83%	

State Probabilities	
Number in system	Probability
0	17%
1	14%
2	12%
3	10%
4	8%
5	7%
6	6%
7	5%
8	4%
9	3%
10	3%
11	2%

Cost of machine 1 =

Cost of machine 2 =

Examples

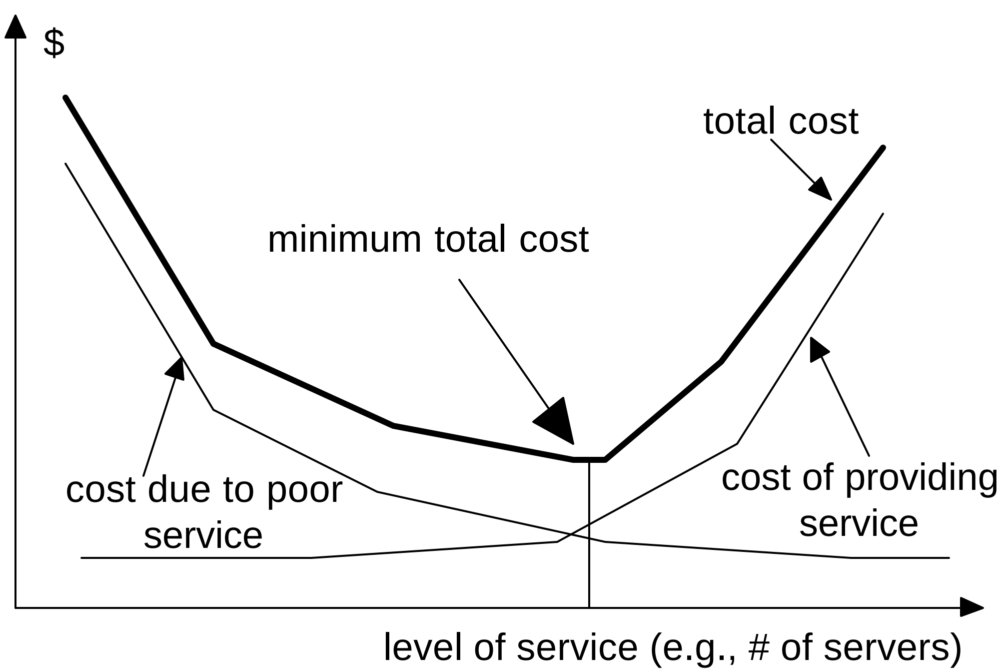
-- of (Potentially) Congested Systems:

System	Customers	Queue: Where the customers wait	Servers
Ski area	Skiers	Next to lifts	Lifts
Talk radio	Callers	On the phone	Radio hosts
Artificial insemination	Parents-to-be	Waiting list	Artificial insemination department
Ambulance service	Patients	At home	Ambulances
Copier repair service	Users of copiers	At work	Repair people
Factory	Raw material	In inventory or in process	Production machines
Airport	Aircraft waiting to land	Circling around	Runway
WWW	Web surfers	At their computers	Web servers

Costs in Congested Systems

- **The cost of providing the service**: Labor costs, depreciation of equipment, etc.
- **Costs incurred because customers have to wait**: Unhappy customers that are less likely to return, inventory costs, etc. These costs are typically difficult to estimate. However, they are very real, and it is probably safe to say that one who ignores these costs will pay them.

The question is what the level of service should be so that total cost is minimized.



Decisions that Impact Total Cost

- One queue or many?
- How many servers?
- Generic or specialized servers?
- Order of service: FCFS, LCFS, Random order, prioritized order, SPT (Shortest Processing Time), EDD (Earliest Due Date).
- Influence customer perceptions: Entertain the customer while waiting, provide estimated waiting times, give maximum service time guarantees.

CASE 1: THE FACULTY CLUB

Part 1

After graduation and a couple of months of R'n'R in Spain, you have accepted a job as Operations Manager at the University Faculty Club. You were hired by the manager, Sven Enquist, who is new himself, having replaced long time manager Rudy Mueller.

During your first week on the job (April 1998), Mr. Enquist asks you to assume responsibility for the Club's once-a-month Saturday evening BBQ. Planning for this event is critical because the club is closed on Sundays so unused food (much of it fresh fruit and vegetables) cannot be used the next day and is often wasted. The key determinate of the profitability of the BBQ is how accurate a forecast can be provided as to the number of people who will attend so that the appropriate amount of food can be purchased and staffing can be arranged for the evening. Because both you and the manager are new, neither of you has a lot of feel for how many people to plan for each month. Because this month's BBQ is only 4 days away, you make a quick trip to the business office and retrieve the records for the last six months. Included in these records is the following data on the number of members who attended each month's BBQ.

Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Sales	127	136	146	68	86	94

Part 2:

You got through the planning for April's BBQ and didn't do too badly, since you used a variety of forecasting techniques to hone in on an estimate for the number of people who would likely attend the event (70 actually attended). However, with more time to plan for May and subsequent months, you have decided to do some more thorough research.

One thing that troubled you when working on the April forecast were the large fluctations from month to month in the limited set of data that you had. This, combined with your intuition that demand for the BBQ was likely seasonal at a club like the Faculty Club, where the academic calendar has a major effect, has led you to gather more data on past demand. You are able to find the following information in the business office on monthly demand over the last three years.

Year	Jan	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
'95	58	72	79	66	46	39	48	59	92	105	124	132
'96	62	82	80	68	53	50	47	64	97	117	131	145
'97	64	88	92	68	59	47	58	67	103	127	136	146

CASE 2: MACPHERSON REFRIGERATION LIMITED

In October, Linda Metzler, newly appointed production planning manager of MacPherson Refrigeration, Ltd. (MRL) of Stratford, Ontario was formulating the production plan for the year beginning on January 1. The plan was to be submitted to the plant's general manager by the end of the month.

Background

MRL has annual sales of about $28.5 million. The company was founded in Stratford in 1954 and it specializes in commercial refrigeration. In 1972, the company opened a new 300,000 square foot plant in Stratford and diversified into the consumer refrigeration market. Subsequently, MRL had added air conditioners to its freezer and refrigerator lines. The company sold its Hercules brand appliances through independent furniture and appliance stores in southern Ontario.

The Stratford Plant

Since 1962, manufacturing efficiency at the plant had increased dramatically through changes in both process design and assembly technology. Annual output per worker had increased from about 240 appliances in 1963 to the present level of about 450 appliances and was expected to be about 480 appliances next year. The Canadian market was too small to allow the productivity levels of American appliance manufacturers, but MRL was considered to be relatively efficient by Canadian standards. The Stratford plant had the physical capacity to make only 13,000 appliances per month.

The Planning Process

Each year in September the marketing and sales department produced a forecast of appliance sales by month for the next year. The production planning department used these forecasts to plan production for the next year. The first step in the planning process was to construct an aggregate production plan which consisted of planned gross production by month for the year. This plan did not indicate numbers of specific appliance types, sizes, or models to be made each month but, as the name indicates, was an aggregate plan. As the production periods approached later in the year, master production plans would be formulated which would be specific regarding appliance type, model number, etc.

The September forecast is presented in each of Exhibits 1-3. It shows the expected seasonal fluctuations and the aggregate number of appliances to be shipped each month. Linda knew that there would be significant variation of specific appliance types within each month but she also knew that each type of appliance required roughly similar materials and labor resources. For aggregate planning purposes then, the number of appliances to be shipped would be sufficient.

The Aggregate Plan

In preparation for her decision, Linda gathered the following information:

1. As of October 1, MRL employed 160 hourly paid unionized production workers. Their two-year contract signed in February of last year called for an increase of $0.75 per hour effective next January 1, bringing the average hourly rate to $10.50. With fringe benefits, the monthly cost to MRL would be about $2,400 per worker. Under the agreement, overtime was 1.5 times the regular hourly rate but not all fringes were affected so a worker-month of overtime costs about $3,300. The standard work week was 40 hours. The aggregate plan in effect until December 31 called for a total production workforce of 160 at that time.
2. The personnel department estimated that hiring, training, and related expenses amounted to $1,800 per new worker. It also estimated a total of $1,200 per worker for severance and other layoff expenses.
3. The accounting department predicted that it would cost about $8 to hold an appliance in inventory for a month during the next year. Raw materials were readily available from regional sources on short notice. The current aggregate plan, supported by marketing's most recent revised forecasts and the master production schedule, predicted an inventory of 240 finished units on December 31.
4. Although MRL manufactured some parts and subassemblies, the plant was primarily a final assembly operation with a throughput time of about three days. The company used an MRP-based planning system. For aggregate planning purposes, management had found that it was adequate to assume that all worker hours scheduled in a particular month would contribute directly to output in the same month. Similarly, experience had shown that no special allowances for learning needed to be considered.
5. There appeared to be three basic tools available to meet demand fluctuations, each of which involved both quantitative and qualitative trade-offs:
   - building inventory to meet peaks
   - using overtime
   - hiring and laying off workers.

The Alternatives

Linda identified three alternative aggregate production plans the company could follow in meeting forecast demand:

1. The production level and the workforce could be held constant throughout the year at a level sufficient to meet the peak demand period. In periods of low

demand inventory would be accumulated and would be drawn down during peak demand periods. Linda was attracted by the protection this plan offered against unforeseen demand changes. This plan is shown in Exhibit 1.

2. The production level could vary to meet demand with a constant workforce by the use of overtime in peak months and restricted output in slow months. The workforce would be held at just the number to meet average monthly requirements. MRL would incur no inventory carrying costs with such a scheme. However, Linda wondered if excessive overtime might lead to lower efficiency or if restricted production might promote poor work habits and low morale. This plan is shown in Exhibit 2.
3. Some of these potential problems could be overcome by a strategy that met demand by varying workforce levels. Linda's calculations showed this to be the cheapest of the three alternatives (see Exhibit 3). However, she was well aware that union relations and employee morale could be adversely affected by frequent layoffs. As well, hiring and training new employees brought their own headaches, especially in a limited labor market such as existed in Stratford.

The Decision

Linda knew that these three very different plans were by no means the only feasible ones available. She realized that her decision on an aggregate plan would involve both quantitative and qualitative trade-offs. One nagging thought in the back of her mind was that no matter which plan she chose, she might never know if a better one existed.

MacPherson Case Exhibits

Exhibit 1: Level Production Plan to Meet Peak Demand

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals
Production Plan													
Shipment forecast	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Production plan	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	101280
Shipments	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Inventory	4280	8320	10760	11200	13040	9680	5120	2360	0	840	3280	6120	75000
Workforce:													
No. of workers	211	211	211	211	211	211	211	211	211	211	211	211	2532
Hirings	51	0	0	0	0	0	0	0	0	0	0	0	51
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0
Worker months overtime	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor capacity	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	8440	101280
Physical Capacity	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	
Cost													
Hiring costs		$ 91,800											
Layoff costs		$ -											
Inventory holding costs		$ 600,000											
Labour costs													
Regular		$ 6,076,800											
Overtime		$ -											
Total Cost		**$ 6,768,600**											

Finished good inventory on December 31 of previous year predicted to be 240 units.

Exhibit 2: Chase Production Plan with Constant Workforce and Overtime

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals
Production Plan													
Shipment forecast	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Production plan	4160	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95160
Shipments	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Workforce:													
No. of workers	199	199	199	199	199	199	199	199	199	199	199	199	2388
Hirings	39	0	0	0	0	0	0	0	0	0	0	0	39
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0
Worker months overtime	0	0	0	1	0	96	126	81	71	0	0	0	375
Labor capacity	7960	7960	7960	8000	7960	11800	13000	11200	10800	7960	7960	7960	110520
Physical Capacity	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	
Cost													
Hiring costs		$ 70,200											
Layoff costs		$ -											
Inventory holding costs		$ -											
Labour costs													
Regular		$ 5,731,200											
Overtime		$ 1,237,500											
Total Cost		$ 7,038,900											

Finished good inventory on December 31 of previous year predicted to be 240 units.

Exhibit 3: Chase Production Plan with Varying Workforce

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals
Production Plan													
Shipment forecast	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Production plan	4160	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95160
Shipments	4400	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95400
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Workforce:													
No. of workers	104	110	150	200	165	295	325	280	270	190	150	140	2379
Hirings	0	6	40	50	0	130	30	0	0	0	0	0	256
Layoffs	56	0	0	0	35	0	0	45	10	80	40	10	276
Worker months overtime	0	0	0	0	0	0	0	0	0	0	0	0	0
Labor capacity	4160	4400	6000	8000	6600	11800	13000	11200	10800	7600	6000	5600	95160
Physical Capacity	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	
Cost													
Hiring costs		$ 460,800											
Layoff costs		$ 331,200											
Inventory holding costs		$ -											
Labour costs													
Regular		$ 5,709,600											
Overtime		$ -											
Total Cost		$ 6,501,600											

Finished good inventory on December 31 of previous year predicted to be 240 units.

CASE 3: BOILIN OIL LTD. REFINERY

One of the earliest and most important applications of linear programming was in the optimization of oil refineries. Today, this remains an important use of LP. The large refineries on the eastern outskirts of this city use large LP's on a weekly basis to determine how to run the complex chemical processes that comprise a refinery. By varying those processes and by varying the types of input crude oil, the refinery manager can change the proportions of the various output products. These products range from premium outputs such as aviation fuel and motor gasoline to the 'heavy end' products such as lubricants and asphalt.

Consider the following simplified version of a real refinery. Boilin Oil Ltd. uses mixes of two types of crude oil to produce two output products, motor gasoline and home heating fuel oil. The refinery operates in two different modes depending on whether Boilin wants to produce more gasoline or more fuel oil. In mode 1 (the 'summer' mode), an input of 1 barrel (bbl) of crude oil A plus 3 bbl of crude B yields an output of 2.5 bbl of gas plus 1 bbl of fuel oil. In mode 2 (the 'winter' mode), 2 bbl of crude A plus 1 bbl of crude B yields 0.7 bbl of gas plus 2 bbl of fuel oil. In any given month, Boilin can operate the refinery in one mode or the other or part of the month in each of the two modes.

In the upcoming month (March), Boilin can obtain up to 100,000 bbl of crude A at $18.00/bbl and 150,000 bbl of crude B at $22.00/bbl. Gasoline is expected to sell for $30.00/bbl in March and fuel oil for $20.00/bbl. Boilin would like to know how to operate the refinery in March so as to maximize profit. Operating costs, apart from the cost of crude oil, are accounted for by material lost in the refining process (as indicated in the numbers above). The only other constraint on the operation of the refinery in March is that Boilin has already signed contracts to deliver 100,000 bbl of gasoline and 75,000 bbl of fuel oil to two different customers. These contracts can not be broken without paying a penalty. Apart from that, the company can use the available crude oil in any combination of modes of operation so as to produce varying amounts of gas and fuel oil (assume all output can be sold at the previously-mentioned prices).

CASE 4: PLANNING FOR EATINS DEPARTMENT STORE

The treasurer of Eatins department store is performing her financial planning for the next six months, September through February. Because of the Christmas season, Eatins needs large amounts of cash, particularly in the months of November and December; and a large cash inflow occurs in January and February when customers pay their Christmas bills. These requirements are summarized in the table (in $000s). The treasurer has three sources of short-term funds to meet Eatins needs. These are:

1. *Pledge Accounts Receivable* A local bank will lend Eatins funds on a month-by-month basis against a pledge on the accounts-receivable balance at the beginning of a given month. The maximum loan is 75 percent of the receivables in a given month. The cost of this loan is 1.5 percent per month of the amount borrowed.
2. *Stretch Payment of Purchases* Payment of purchases can be delayed one month. Thus, for example, the $100,000 planned for payments for November could be delayed until December, and Eatins could use the funds to meet November needs. When purchase payments are thus stretched, Eatins loses the 3 percent discount it normally receives for prompt payment.
3. *Use Short-Term Loan* A bank is willing to lend Eatins any amount from $40,000 to $100,000 on a six-month basis. The loan would be taken out in full in the beginning of September for a fixed amount and paid back in full at the end of February. It would not be possible to add to the loan or to pay off part of the loan during the period. The cost of the loan would be 1 percent per month, payable each month.

In any period, if the firm has excess funds, they can be invested in short-term government securities that return 0.5 percent per month.

The objective of the treasurer is to minimize the net interest cost to Eatins while meeting the firm's cash needs.

	Sept.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**
Accounts receivable balance (at beginning of month)	$70	$50	$70	$120	$100	$ 50
Planned payments of purchases (on assumption that discount is taken)	80	90	100	60	40	50
Cash needs for operations	-	30	60	90	-	-
Cash surplus from operations	20	-	-	-	30	150

CASE 5: SANTIAGO ELECTRIC

You are the manager of a coal-fired power plant which is scheduled to produce 1,300,000 calories for the upcoming season. You are considering nine possible fuel types for the power plant. The table below contains information on price, energy content and emitted pollutants for each type of coal. Your must decide which fuel(s) to use in the power plant. It is possible to purchase fractional tons, and it is also possible to mix coal from different sources in the power plant.

Coal type	Price/ton	Calories/ton	SO2 (kg/ton)	CO2 (kg/ton)
Virginia 1	$440	1320	66	165
Virginia 2	$550	1540	55	165
Australia A	$440	1485	72	132
Australia B	$682	1595	50	121
Russia	$429	1265	72	154
Ukraine	$462	1375	77	171
China L	$385	1100	110	220
China M	$429	1298	66	198
China H	$517	1386	61	160

In addition to keeping costs low, you need to ensure that you satisfy environmental regulations regarding emission of SO_2 and CO_2.

You are also wondering how various pollution-reduction measures will affect your operation. One procedure is to have the coal "washed" prior to burning. This cleaning procedure reduces the SO_2 emissions of each coal type by one-third. Another possibility is that the provincial government may create a market for carbon emission permits.

CASE 6: PRODUCTION PLAN AT WESTPLAST LTD.

Note: This case is written by E. Erkut, based on the experience of a student in the Cooperative Education program at the Faculty of Business (University of Alberta). The name of the company and its customers, the numbers throughout the case, as well as the final decision taken by the company, have been changed for confidentiality reasons. The product names and descriptions have been masked as well to prevent identification of the industry and the company.

Introduction

WestPlast Ltd. operates a chemical factory in Alberta, which produces plastic pellets using recycled plastic. The pellets are used as raw material in many industries in Canada and the USA. With the current high demand for pellets around the globe, WestPlast is in an enviable position. Demand for their products is such that their manufacturing capabilities cannot keep up. Hence, this company must be very selective about its product mix.

Although the company is able to produce a large number of different products, changing between products reduces production efficiency. The pellets are produced in a continuous chemical process. Different types of pellets are produced based on the composition of the chemicals that are added to scrap plastic. The continuous nature of the production process implies that the operators must continue production as they change from one product to another. As the specifications are adjusted continuously, some amount of pellets is produced that does not satisfy the specifications for any of the products demanded. This output has to be scrapped. Although the scrap can be reused as raw material, as a result of producing scrap the production capacity is reduced and production costs go up. Hence, the company wishes to be selective in determining its product mix to reduce inefficiencies resulting from switching between products.

The products considered are as follows:

- **Pellet A:** This product has proven to be WestPlast's strength over the years. Pellet A production consists of two classes, A1 and A2. WestPlast satisfies almost all of the Canadian demand for pellet A2, and there is some export potential as well. The specifications for pellets that are exported are slightly different from pellets sold in Canada.
- **Pellet B:** Altoil, an Edmonton-based company is the sole user of this product in Canada, and this company receives all of its raw material from WestPlast.
- **Pellet C:** This product is used in various industries, and carries considerable export potential. Again, the specifications for exported pellets are different from pellets that are sold domestically.
- **Pellet D:** Demand for this product has been growing. WestPlast is a majority supplier to Smitheren Ltd., a Calgary company.

- **Pellet E:** This product carries a significant profit potential due to a significant increase in its price over the last two years. However, it takes more time and effort to produce than the other pellets.
- **Pellet F:** There are two main products in this category: F1 and F2. WestPlast is the sole supplier of pellet F2 to a Calgarian operation, Calcan.

Relevant Constraints

The demand for the products of WestPlast exceeds its production capacity. This implies that the company is foregoing revenues. However, plant expansion or considerable process improvement are not viable options at this time due to a lack of capital. Therefore, the company must operate within its technological limitations. The current annual capacity is estimated to be 335,000 tons. Revenue maximization must come from an effective product mix selection under this constraint.

The determination of the annual capacity is not a trivial task. In fact, WestPlast's production capacity could be as high as 400,000 tons per year if there were no inventory considerations. This figure could be achieved if the plant produced all of the annual demand in one product in one batch, minimizing product changeovers which reduce production efficiency. However, this strategy is not realistic, since it would require carrying huge inventories either at WestPlast or at the customer's location. Neither WestPlast nor its customers are willing to carry this inventory. Consequently, the minimal inventory strategy used has a negative effect on the plant capacity. The figure 335,000 tons is an estimate based on past years' performances, and a reasonable number of product switches during the year. Although the total production at the end of the year may be somewhat higher or lower, it is expected to be within 5% of this estimate.

Contractual obligations make up the second factor that limits the choices of WestPlast in designing a product mix. Much of the production capacity (about 57%) is already allocated to customers with which relationships have been established. WestPlast must satisfy these requirements, and is left with a discretionary balance to work with. Nevertheless, WestPlast is relatively happy to have these obligations since they provide an assured source of revenue. The contractual obligations are:

WestPlast Contractual Obligations			
Company	*Pellet*	*Projected demand*	*% of Capacity*
Colpop	A1	135,000 tons	40.3%
All of Canada	A2	30,000 tons	8.9%
Altoil	B	16,000 tons	4.8%
Calcan	F2	10,000 tons	3.0%

The final constraint is delivered by the potential sales projections. Given that WestPlast cannot meet the total demand, it makes no sense to produce too much of one product. This would not only imply lost revenues due to not producing an alternate product, but also increased inventory costs. Based on past demand and economic forecasts for next year, the potential demand has been estimated for each product under consideration. These projections can be found in the final table.

Production Criteria

Several factors come into play when deciding on a product mix. Some are easily quantifiable, while others are based on subjective judgment. WestPlast has decided to consider two criteria explicitly: relative unit revenue, and plant capability index. The relative unit revenue is based on current selling prices of the products. The most-expensive product is assigned a relative unit revenue of 100, and all other products are rated accordingly. This criterion quantifies the revenue maximization goal of the company.

The plant capability index (PCI) is a company-specific index, which quantifies the desirability of a product from a production perspective. Five subcriteria are used to compute this index: plant output rate, quality compared to industry standards, raw material quality needed, overhead burden, and process aggravation. Each of these five subcriteria is associated with a weight, which represents its relative importance. These weights vary between 10% and 30%, adding to 100%. The weights are decided by a consensus of the managers, and the company assumes that the weights accurately reflect the relative importance of each subcriteria. To compute the PCI for each product group, the product group is given a score from 1 to 100 for each subcriterion and these scores are then combined with the subcriteria weights. The closer the PCI is to 100, the more desirable the product from a production perspective. WestPlast wishes to maximize the average PCI of the product mix. In addition, WestPlast has a policy of not producing a product with an index value lower than 50. The next table summarizes the PCI, relative unit revenue, and the projected demand for the products under consideration. If a product is offered in Canada, as well as exported to the USA, it is listed as two separate products, since the relative unit revenues are different and the specifications are slightly different for exported pellets. The products are listed in decreasing order of relative unit revenue.

WestPlast Product Revenue Breakdown				
Pellet	*Market*	*Index*	*Revenue*	*Demand (tons)*
E	Canada	63	100.0	30,000
B	Altoil	58	81.1	16,000
C	Canada	65	69.8	30,000
A1	Colpop	78	67.3	135,000
C	Export	62	65.8	70,000
A2	Canada	78	61.6	30,000
F2	Calcan	65	57.7	10,000
D	Local	65	57.4	35,000
A2	Export	78	51.6	20,000
F1	Canada	85	35.8	50,000

CASE 7: CLEARCUT INC.

Ken Douglas wrote this case with supervision by Armann Ingolfsson. The case is based on a MGTSC 541 class project. The name of the company and the data have been disguised.

Introduction

With the explosion of media coverage and the rise in public awareness of the waste and disregard for the environment that some companies have shown in the past, the forestry industry has been forced to find more effective (and “environmentally friendly”) harvesting strategies. To increase the urgency for forestry companies, a reduction of government timber quotas has created a need to streamline operations. This movement has included experimenting with new and more efficient harvesting systems and developing new strategic planning methods.

Company Background

Clearcut Inc. is a large family-owned company with interests in forest resources. Located in Spruce Plain, Alberta, Clearcut’s operations division is comprised of a woodlands operation and manufacturing facilities (*Sawmill and Oriented Strand Board Mill*). As a consistent leader in the industry, Clearcut is a firm that is looking to the future by searching for ways to optimize its harvesting techniques.

The most commonly used harvesting system is the full tree, or *tree-length* (T/L) harvesting system. In the full tree system, a *feller buncher* cuts the trees, laying the harvested trees in piles. A *skidder* then collects the logs and drags them to the roadside, where the *delimber* removes the branches from the stems. Finally, the trees are loaded onto a logging truck and trailer, and delivered to the mill.

The Spruce Plain operation relies on wood to be delivered to the mill in a timely and consistent manner. In an attempt to improve the efficiency of the wood delivery, Clearcut has begun to experiment with a different type of harvesting and delivery system, the *cut-to-length* (C/L) system. Clearcut began to use this innovative system in 1991. This system was developed in Sweden and is more efficient because much of the processing is done at the stump instead of at the roadside. Due to the development of a new piece of equipment called a *harvester*, the trees can be felled, delimbed, and cut to a predetermined length in one handling, right where the tree is felled. This makes it possible to load the logs onto a trailer at the harvester making the transportation to the road more cost effective. For most species of tree this system guarantees higher recovery yields.

Clearcut purchases the rights or quotas to harvest timber in Alberta’s forests from the Government of Alberta. These quotas are determined based on forest inventory studies done by the government. When the studies are completed, the forest is partitioned into small blocks, or “stands,” consisting of common species composition and tree size. The rights to the stands are then sold to the forestry companies based on estimates of species content and overall precut timber volume in each stand. Given that Clearcut is allowed by the provincial government to purchase the rights to a limited volume of timber per year, it is imperative that the company maximizes the harvesting efficiency of its quota. With the introduction of the revolutionary cut-to-length harvesting system, the company is presented with a relatively new and extremely efficient logging option. The choice and relative proportion of usage between the two systems has become a paramount decision for Clearcut.

To simplify the coordination and control within each stand, Clearcut awards a single company the contract for each stand. This means that only one system operates on each stand. The differential between the yields of the two systems is an important financial concern for the organization because the volume quotas are based on precut estimates and not on final harvest yields. Although the new system has demonstrated a dramatic improvement in yield volume, harvesting contractors have been slow to respond to the innovation because of the high capital cost of switching. As a result, many still maintain the traditional tree-length equipment.

At the present time in Alberta, the number of harvesting contractors that have implemented the cut-to-length system is insufficient to produce the amount of timber that Clearcut desires. An added complication is that Clearcut has entered into long-term contracts with many of the companies that still utilize the old system, guaranteeing them minimum volumes for the next few years. The fact that the industry is in transition has also made Clearcut realize that it is imperative for future operations to keep its best contractors busy until they switch to the new system, so that when they do switch, the business relationships that have taken years to develop will be maintained.

With all of this said, Clearcut must keep its mill operating at full capacity. Due to the high costs of downtime and the inefficiencies of operating under capacity, the company must ensure that the volume of timber that reaches its mill is adequate to ensure optimal lumber, pulp, and paper production. It would be nice to be able to keep all of its contractors ‘happy,’ but the reality that output yield favors the new cut-to-length system necessitates that this system must be utilized to maximize the value of the quotas.

Problem Statement and Questions:

Currently Clearcut has a total of 50 stands that it has purchased the rights to choose from for the upcoming year. Although Clearcut has purchased the rights to all 50 stands, there is a limit of 2 million cubic metres of precut volume they can harvest. The Provincial Government sets this limit.

Clearcut would like to harvest at least 1.7 million cubic metres (measured in actual harvest yields rather than precut volume) to keep its mill busy. In order to keep all of its contractors happy, Clearcut management has estimated that it must ensure that

400,000 cubic metres (again, measured in actual harvest yields) must be allotted for each of the systems so as to fulfill contracts and maintain goodwill.
Below is a table of the relevant prices, costs and yields for each of the tree species found in Alberta. The costs and prices are given per cubic meter of harvest yield. The yields are given as a percentage of precut volume. The workbook Clearcut.xls (will be available from the course web) contains detailed data about each of the 50 stands.

	Timber Species			
	Black Spruce (Sb)	White Spruce (Sw)	Lodgepole Pine (Pl)	Aspen (Aw)
Price ($/m^3)	70	100	80	50
Cost ($/m^3)	40	40	40	40
T/L Yield (%)	90	90	90	85
C/L Yield (%)	85	95	95	80

CASE 8: LOT SIZING AT ALTAMETAL LTD.

Note: This case is written by E. Erkut, based on the experience of a student in the Cooperative Education program at the University of Alberta. The name of the company and its customers, the numbers throughout the case have been changed for confidentiality reasons.

AltaMetal Ltd. is a local company that produces a variety of steel products. The end products of AltaMetal are used as raw materials in a number of different industries. The total number of products offered by AltaMetal is over 1,000. To simplify production planning, AltaMetal has aggregated these products into 9 groups. The monthly demand (in kg.) for each product group has been estimated by using data from the last three years. The positive trend in the past data implies that AltaMetal will have its best year in terms of sales next year. The plant capacity is 90,000 kg. per day.

AltaMetal Ltd. Estimated Monthly Demand (kg.)

	JAN	*FEB.*	*MAR*	*APR*	*MAY*	*JUN.*	*JUL.*	*AUG.*	*SEP.*	*OCT.*	*NOV.*	*DEC*
A	281423	340504	613968	785612	1027663	680248	417939	387932	397467	549204	378037	108740
B	12958	17235	9307	52177	62513	7890	11832	191006	133779	70846	21390	20869
C	28135	37790	25986	40029	15842	102361	434372	610393	898305	469775	31797	42454
D	75391	203782	239928	242175	101781	482309	514289	928632	609791	544354	201298	168349
E	35255	89769	62656	90529	11443	104344	228747	289783	252327	233185	69619	63348
F	501115	735942	1507658	1099324	830959	575237	476024	740518	948067	770591	438590	215566
G	349877	291881	487099	347574	357612	573767	399809	261755	293997	548693	431447	85176
H	13978	39975	45421	73161	43045	65251	51578	104037	77862	294468	39843	34785
I	9150	12794	18215	22463	11606	102315	169644	353220	1135293	734317	39226	27982

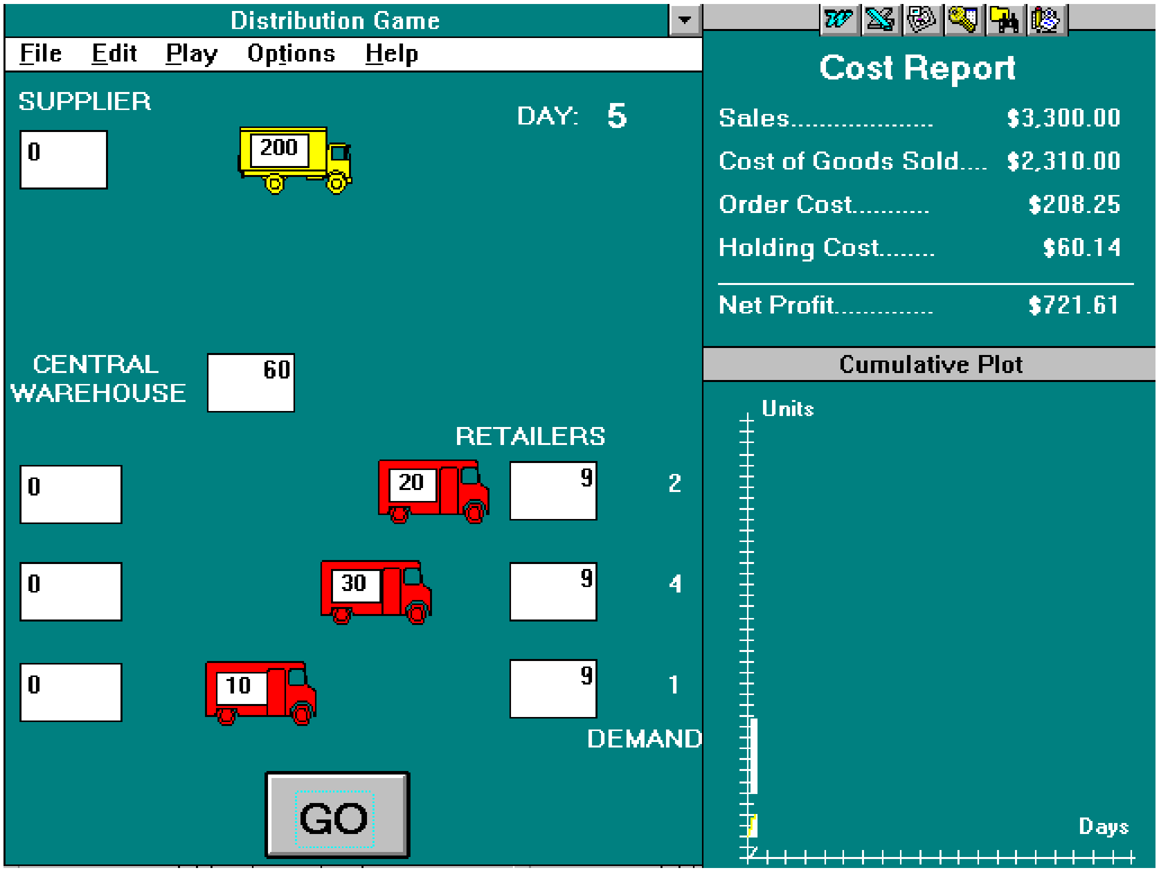
Part 1:

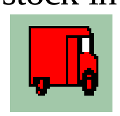
Is it possible for AltaMetal to satisfy the projected demand in 1996? If so, present a feasible production plan. (assume 'round-the-clock operation)

Part 2:

In Part 1, we assumed that production followed demand (i.e., we could produce as much or as little of a product as we wanted). This is undesirable, since it may lead to small lot sizes and frequent switching between products. Switching between products requires setups, and setups consume time, reducing available capacity. If the switching is excessive, the given plant capacity may not apply. AltaMetal wishes to know whether it is possible to produce each product in lot sizes of 30 tons, i.e., whenever the plant starts producing a product, the production must be in multiples of 30 tons. This implies that three lots will be produced every 24-hours, and there will be at most three setups (product changes) in any 24-hour period. This will reduce the number of setups but it will also force higher inventories. Evaluate the impact of this strategy for AltaMetal. What amount of additional inventory must be carried?

CASE 9: DISTRIBUTION GAME



This is an educational game designed to interest you in the problems of ordering and allocating stock in multi-level distribution systems. To run it, double-click the red truck icon  in the "business" program group on the computers in B-26 and B-28.

As shown on the diagram above, the game has an on-line 'Help' function. Select the 'Help Menu' and browse the 'Help Index' to learn more about how (and why!) the game is played.

You are asked to develop an ordering policy for the retailers and another policy for the central warehouse. An ordering policy consists of a reorder point ROP and an order quantity Q. As an example, consider the retailer closest to the bottom of the screen. Each day, *the inventory position* I should be computed as "stock on hand + stock on order." If I > ROP, then no order should be placed that day. If I ≤ ROP, then an order of size Q should be placed that day.

Note that the ordering policy should be applied separately for each retailer and for the central warehouse.

For your information, here is some additional information about how the distribution game works (use edit → view parameters to see this information while playing the game).

- Supplier to warehouse transit time: 15 days
- Warehouse to retailer transit time: 5 days
- Daily demand per retailer: equally likely to be 0, 1, 2, 3 or 4 units. Mean = 2 units per day, standard deviation = 1.414 units per day. (The view parameters dialog box says the variance is 4, which would imply a standard devation of $\sqrt{4} = 2$, but this is incorrect).
- Selling price: $100 per unit.
- Purchase price: $70 per unit.
- Supplier to warehouse fixed order cost: $200
- Warehouse to retailer fixed order cost: $2.75
- Warehouse holding cost rate:
  $0.21/purchase $/year = ($70/unit)($0.21/purchase $/year)
  = $14.7/unit/year = ($14.7/unit/year)/(365 days/year) = $0.040/unit/day
- Retailer holding cost rate:
  $0.25/purchase $/year = ($70/unit)($0.25/purchase $/year)
  = $17.5/unit/year = ($17.5/unit/year)/(365 days/year) = $0.048/unit/day

CASE 10: RED DOG BEER COMPANY

The following case is fictional. It was written by Armann Ingolfsson, with help from Jianjun Zhang (who extracted the data), Jeff Borschowa and Chris Neuman.

The Red Dog Beer Company has operated in Alberta for 50 years. The company's lone brewing and bottling facility is located in Calgary and beer is transported by truck throughout the province from the Calgary facility. This facility is 20 years old and production technology has improved significantly since it was built.

Recently, Red Dog received an offer from a large retail chain to purchase the Calgary facility. The annualized equivalent of the offer is $200,000.

Red Dog management sees the offer as an opportunity to modernize and reorganise its production and distribution system, with the aim of reducing overall costs.

A recently completed feasibility study for a new facility in Edmonton estimates an annualized capital and operating cost of $460,000 for a facility that could produce 2,750 truckloads of beer per year. For comparison, the current Calgary facility has the capacity to produce 2,400 truckloads per year. The production cost per truckload for the proposed Edmonton facility is estimated at $410 per truckload, compared to $515 for the current Calgary facility. The feasibility study also considered a new Calgary facility, with a 2,900 truckloads per year capacity and a production cost of $380 per truckload. The annualized capital and operating cost of such a facility would be $615,000. This is higher than the cost in Edmonton due to higher real estate prices in Calgary.

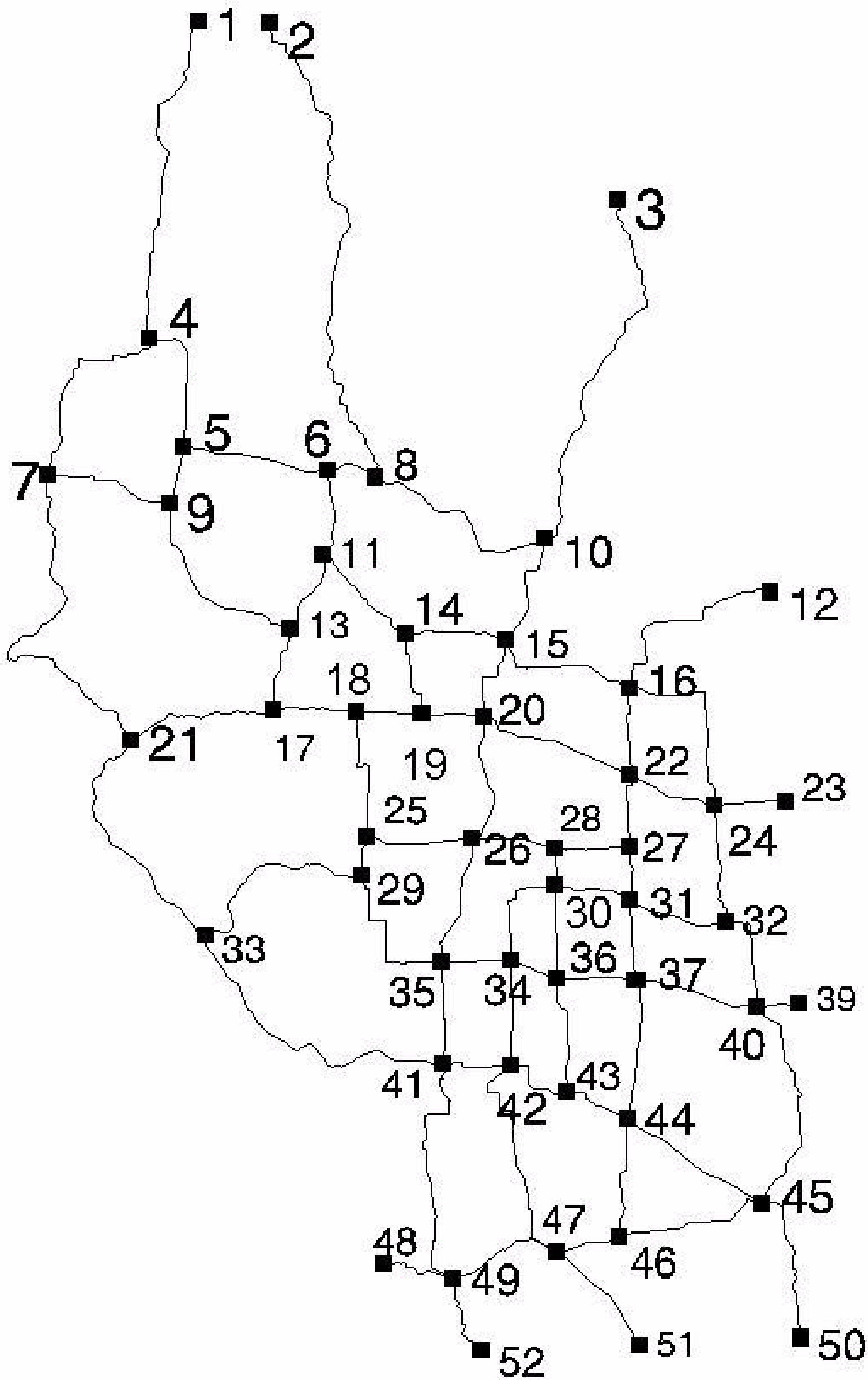
Two smaller facilities in Red Deer and Lethbridge were also considered in the feasibility study. The Red Deer facility has an annual capacity of 715 truckloads per year, a production cost of $450 per truckload and an annualized capital and operating cost of $160,000. The Lethbridge facility has an annual capacity of 650 truckloads per year, a production cost of $460 per truckload and an annualized capital and operating cost of $150,000.

Assuming that the company accepts the offer for the Calgary facility, Red Dog needs to make three kinds of decisions:

1. Where to build new production/distribution centers,
2. Which regions of the province to serve from which centers, and
3. What routes to use in transporting the beer from a center to the cities and towns in its region. For simplicity, assume that trips to different population centers cannot be combined. In other words, a truck can have only one destination. Note that this is a simplification of the actual distribution process.

Average consumption of Red Dog beer in the recent past has been about 1 truckload per 1,000 people throughout Alberta. Transportation costs are estimated to be $1 per km per truckload.

You will be provided with a data file that contains a list of most road segments in Alberta (see map on next page). For each road segment, you are told what the beginning and ending nodes are and the length of the segment in kilometers. Each road segment is listed twice (once in each direction). The data file also contains a list of nodes, with populations. For simplicity, we ignore population along road segments and people that live far from a road. The total of the node populations includes about 80% of the Alberta population.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CASE 11: THE BLOODLESS COUP CONCERT

John Aaron had just called the meeting of the Programs and Arts Committee of the Student Government Association to order.

“Okay, okay, everybody, quiet down. I have an important announcement to make,” he shouted above the noise. The room got quiet and John started again. “Well you guys, we can have the Coup.”

His audience looked puzzled and Randy Jones asked, “What coup have we scored this time John?”

“The Coup, the Coup! You know, the rock group, the Bloodless Coup!”

Everyone in the room cheered and started talking excitedly. John stood up, waved his arms, and shouted, “Hey, calm down everybody and listen up.” The room quieted again. “The good news is that they can come.” He paused a moment. “The bad news is that they will be here in 19 days.”

The students groaned and seemed to share Jim Hasting's feelings, “No way, man. It can't be done. Why can't we put it off for a couple of weeks?”

John answered, “They're just starting their new tour and are looking for some warm-up concerts. They will be traveling near here for their first concert date in Vancouver and saw they had a letter from us, so they said they could come now--but that’s it, now or never.” He looked around the room at the solemn faces. “Look you guys, we can handle this. Let's think of what we have to do. Come on, perk up. Let's make a list of everything we have to do to get ready and figure out how long it will take. Somebody tell me what we have to do first!”

Anna Mendoza shouted from the back of the room, “We have to find a place; you know, get an auditorium somewhere. I've done that before, and it should take anywhere from 2 days up to 7 days, most likely about 4 days.”

“Okay, that's great,” John said as he wrote down the activity “secure auditorium” on the blackboard with the times out to the side. “What's next?”

“We need to print tickets,” Tracey Shea blurted. “It could only take a day if the printer isn't busy but it could take up to 4 days if they are. It should probably take about 2 days.”

“But we can't print tickets until we know where the concert will be because of the security arrangement,” Andy Taylor noted.

“Right,” said John, “get the auditorium first then print the tickets. What else?”

“We have to negotiate with the local union for concert employees, stagehands, and whomever else we need to hire,” said Reggie Wilkes. “That could take a day or up to 8 days, but 3 days would be my best guess.”

“We should probably also hold off on talking to the union until we get the auditorium,” John added. “That will probably be a factor in the negotiations.”

“After we work things out with the union we can hire some stagehands,” Reggie continued. “That could take as few as 2 days but as long as 7. I imagine it’ll take about 4 days. We should also be able to get some student ushers at the same time once we get union approval. That could take only a day, but it has taken 5 days in the past; 3 days is probably the most likely.”

“We need to make hotel and transportation arrangements for the Coup,” Jim Hastings said. “But we better not do that until we get the auditorium. If we can't find a place for the concert, everything falls through.”

“How long do you think it will take to make the arrangements?” John asked.

“Oh, between 3 and 10 days, probably about 5, most likely,” Jim answered.

“We need to arrange a press conference,” said Art Cohen, leaning against a wall. “This is a heavy group, big-time.”

“But doesn't a press conference usually take place at the hotel?” John asked.

“Yeah, that's right,” said Art. “We can't make arrangements for the press conference until we work things out with the hotel. When we do that it should take about 3 days to set up a press conference, 2 days if we're lucky and 4 at the most.” The room got quiet as everyone thought.

“What else?” John said.

“Hey, I know,” said Annie Rework “once we hire the stagehands they have to set up the stage. I think that could be done in a couple of days, but it could take up to 6 days, with 4 most likely.” She paused for a moment before adding, “And we can also assign the ushers to their jobs once we hire them. That shouldn't take long, maybe only a day, 3 days at worst. Most likely about 2 days.”

“We also have to do some advertising and promotion if we want anyone to show for this thing,” said Art nonchalantly. “I guess we need to wait until we print the tickets first so we'll have something to sell. That depends on the media, the paper, and radio stations. I've worked with this before. It could get done really quick, like 2 days, if we can make the right contacts, but it could take a lot longer, like 12 days if we hit any snags. We probably ought to count on 6 days as our best estimate.”

“Hey, if we're going to promote this shouldn't we also have a preliminary act, some other group?” said Annie.

“Wow, I forgot all about that,” said John. “Hiring another act will take me between 4 and 8 days; I can probably do it in 5. I can start on that right away at the same time you guys are arranging for an auditorium.” He thought for a moment. “But we really can't begin to work on the promotion until I get the lead-in group. So what's left?”

“Sell the tickets,” shouted several people at once.

“Right,” said John, “we have to wait until they are printed; but I don't think we have to wait for the advertising and promotion to start do we?”

“No,” said Jim, “but we should hire the preliminary act first so people will know what they're buying a ticket for. The name of the preliminary act should be printed on the tickets also.”

“Agreed,” said John. “The tickets could go quick; I suppose in the first day.” “Or,” interrupted Mike Eggleston, “it could take longer. I remember two years ago it took 12 days to sell out for the Cosmic Modem.”

“Okay, so it's between 1 and 12 days to sell the tickets,” said John, “but I think about 4 days is more likely. Everybody agree?”

The group nodded in unison and they all turned at once to the list of activities and times John had written on the blackboard.

APPENDIX: EXCEL & SOLVER

Introduction

This appendix is meant to introduce you to some of the more powerful and timesaving features of Microsoft Excel, in particular the Solver. We will cover the following topics:

- Spreadsheet Design Goals & Guidelines
- Shortcuts in Excel
- Excel's built-in functions
- Data tables (one-way & two way)
- Solver
- Visual Basic for Applications

Spreadsheet Design Goals

- Communication – a spreadsheet should be laid out in a 'readable' way that communicates the relevant aspects of the problem at hand in as clear and intuitively appealing a manner as possible.
- Reliability – the output a spreadsheet generates should be correct and consistent. This has an obvious impact on the degree of confidence the user places in the model.
- Auditability – the user should be able to retrace the steps followed to generate the different outputs from the model in order to understand the model and verify results.
- Modifiability – the ability to change or enhance the spreadsheet in order to meet dynamic user requirements.

Spreadsheet Design Guidelines

- **Do not embed numeric constants in formulas**. Numeric constants should be placed in individual cells and labeled appropriately. This enhances the reliability and modifiability of the model.
- Organize the data, and then build the model around the data. Once the data is arranged in a visually appealing manner, logical locations for decision variables, constraints and objective function tend to naturally suggest themselves. This also tends to enhance the reliability, auditability and maintainability of the model.
- Things which are logically related (e.g., left-hand-sides and right-hand-sides of constraints) should be arranged in close physical proximity and in the same

columnar or row orientation. This enhances reliability and auditability of the model.

- A design that results in formulas that can be copied is probably better than one that does not. A model with formulas that can be copied to complete a series of calculation in a range is less prone to error (or more reliable) and tends to be more understandable (or auditable) (i.e., once the user understands the first formula in a range, he/she understands all the formulas in a range).
- Column or row totals should be in close proximity to the columns or rows being totaled. Spreadsheet users often expect columns and/or rows to be totaled. Numbers at the ends of columns or rows that do not represent totals can easily be misinterpreted (reducing auditability).
- The English-reading human eye scans left to right, top to bottom. This fact should be considered and reflected in the spreadsheet design to enhance the auditability of the model.
- Use shading, borders and protection to distinguish changeable parameters from other elements of the model. This enhances the reliability and modifiability of the model.
- Use text boxes and cell notes (and even voice messages!) to document various elements of the model. These devices can be used to provide greater detail about a model or particular cells in a model than labels on a spreadsheet may allow.

(From Cliff T. Ragsdale)

Shortcuts in Excel

Excel offers many keyboard shortcuts to the advanced user. Here are 10 shortcuts that we find indispensable and may save you from premature arthritis in your mouse finger ☺. Most of these shortcuts involve pressing the ‘Ctrl’ key and some other key simultaneously.

- Workbooks – ‘Ctrl+n’ creates a new workbook. ‘Ctrl+o’ opens an existing workbook. ‘Ctrl+s’ saves the currently open workbook.
- Propagating – Select the cell you want to propagate. Move the cursor over the lower right corner of the cell, until it turns into a plus. This is the *cell handle*. Double-click the cell handle. This will propagate the formula in the cell down the column for as far as there are numbers in the adjacent column.
- Moving around quickly – Try holding down the ‘Ctrl’ key while using the arrow keys (left, up, down, or right). The cursor will move as far as it can before the cells change in some way. For example, if you have selected a cell somewhere in a table of numbers then this will bring you to one edge of the table. Caution: if most of the cells are empty pressing ‘Ctrl-down’ will likely bring you to row 65,536 (the last row) and ‘Ctrl-right’ will bring you to column

IV (the last column). Press 'Ctrl-up' or 'Ctrl-left' to get back to where you were.

- Selecting cells – Hold down the 'Shift' key and use the arrow keys to move around, and all the cells you pass over will be selected. This is a real time-saver in combination with the 'Ctrl' key.
- Move between worksheets – 'Ctrl+Page Up' and 'Ctrl+Page Down' moves between the worksheets in a workbook.
- Move between workbooks – 'Ctrl+Tab' cycles between open workbooks.
- Formatting cells – 'Ctrl+b,' 'Ctrl+u,' and 'Ctrl+i' formats text & numbers as bold, underlined, or italic, respectively.
- Summing cells – If you just need a quick and dirty sum of numbers, select the cells with the numbers, and the sum automatically appears in the bottom-right corner of the Excel window. Right click where the sum appears and you can change it to display another useful quantity, such as the average.
- Undo changes – 'Ctrl-z' undoes the most recent change you made. If you have to undo several changes, keep pressing 'Ctrl-z' until you have undone as many changes as you need (Excel remembers the last 16 changes you made).
- Repeat an action – If you need to repeat an action, press 'Ctrl-y.'

Excel's Built-in Functions

Excel has many built-in functions – far more than you find in any programmable calculator. By taking advantage of these, you can save yourself time and hassle. All of the functions can be accessed from the Function Wizard, where you can also find detailed information about how each function works. Here are some of the best:

- MIN, MAX – the maximum and minimum of a range of numbers.
- ABS – the absolute value of a number.
- SUM, SUMPRODUCT – returns the sum of a range of numbers, and the sum of the products of two ranges of numbers, respectively.
- AVERAGE, MEDIAN – the average and median of range of numbers.
- ROUNDUP, ROUNDDOWN, ROUND – rounds numbers up, down, and to an arbitrary number of decimal places.
- COUNT, COUNTIF - counts numbers in a range, or counts only those number that satisfy a given criteria.
- RAND – returns a random decimal number between 0 and 1. Any number between 0 and 1 is equally likely to be returned, that is, the number comes from a uniform distribution.
- IF – lets you perform a logical test and the test returns TRUE do one thing, otherwise do something else.
- AND, OR, NOT – allows you to chain logical tests in statements. For example, you can use these functions inside an IF function.

- FREQUENCY – calculates the frequency distribution for a range of numbers, that is, how many numbers fall into each of several specified bins.

More information on all of these functions is available from the Excel on-line help (access by clicking the '?' icon in the function wizard).

Data Tables

Data tables are a useful Excel feature that can be used to see how the value calculated by a complex formula depends on one or two of the "inputs," i.e., numbers somewhere in the spreadsheet that affect the outcome of the formula. There are two types of Data Tables: one-way and two-way.

One-Way Data Tables

One-way data tables allow you to see how one or more formulas depend on one input.
Example:

	A	B	C	D
1	x	y	x+y	x-y
2	1	2	3	-1

Cells A2 and B2 contain numbers. Cell C2 contains the formula A2+B2 and D2 contains the formula A2-B2.

Suppose you want to generate a table that shows how the values in cells C2 and D2 change as the number in cell A1 varies from 1 to 5. To do this, first type the numbers 1 to 5 in cells A5:A9, type the formula =C2 in cell B4, and the formula =D2 in cell C4, as shown below (in formula view).

	A	B	C
3	x	x+y	x-y
4		=C2	=D2
5	1		
6	2		
7	3		
8	4		
9	5		

Now, highlight the range A4:C9, choose Table … from the Data menu, enter A2 for the column input cell, and nothing for the row input cell. Hit OK and you should see

	A	B	C
3	x	x+y	x-y
4		3	-1
5	1	3	-1
6	2	4	0
7	3	5	1
8	4	6	2
9	5	7	3

Note:

- This example had two outputs. A one-way table can have any number of outputs.
- Physically, what the computer does to fill in the table is take the numbers 1 through 5, one at a time, plug them into cell A2 (the column input cell), see what values are taken on by the formulas in cells B4 and C4 and record those values in the appropriate row in the table. If your computer is slow enough, you may be able to see the different values being put into cell A2.
- It's also possible to have the input values (1 to 5) in a *row* at the top of the table, instead of in a column at the left of the table. If you do this, you would specify the *row input cell* and leave the column input cell blank.
- After you have generated a table, you can change the input values and the table will automatically recalculate. For example, you could change the numbers in cells A5:A9 above and the numbers in cells B5:C9 would automatically recalculate.

Two-Way Data Tables

Two-way Data Tables allow you to see how **one formula** depends on **two inputs**.
Example:

	A	B	C	D
1	x	y	x+y	x-y
2	1	2	3	-1

As before, cells A2 and B2 contain numbers. Cell C2 contains the formula A2+B2 and D2 contains the formula A2-B2.
Suppose you want to see how the value in cell C2 changes as you vary the numbers in cells A2 and B2 from 1 to 3. To do this, type what is shown below in formula view:

	A	B	C	D
4	=C2	1	2	3
5	1			
6	2			
7	3			

Highlight the range A4:D7, choose Table … from the Data menu, enter A2 for the column input cell, and B2 for the row input cell. Hit OK and you should see

	A	B	C	D
4	3	1	2	3
5	1	2	3	4
6	2	3	4	5
7	3	4	5	6

Cautions

- The row and column input cells for a table must be on the same worksheet as the table itself. Sometimes this is inconvenient, so here is a trick to get around this:
    - Suppose the table is in sheet “tablesheet” while the calculations you are interested in are in sheet “calculationsheet”.
    - Pick a cell in “tablesheet” to be the row input cell, for example A1.
    - Go to “calculationsheet.” In the cell that you really want to be the row input cell, type the formula =’tablesheet’!A1.
    - Do the same for the column input cell if necessary (but use a different cell!).
- If you generate a large table, it may take a long time to recalculate any time you make a change to your spreadsheet. To avoid this, you can do “Tools -> Options -> Calculation -> Automatic except tables.” The table will then only be recalculated when you press the F9 key. Or, you can “Freeze” the numbers in the table by copying them and then pasting them as values.
- Once you have generated a table, you cannot delete parts of it – if you want to delete it you must delete the whole table.

Using Data Tables to Replicate a Simulation

One use for data tables is to “trick” Excel into recalculating the random numbers in a simulation, collect the output measures we specify, and repeat this a set number of times. To do this, we normally use a one-way Data Table. The outputs are whatever measures we want to keep track of for each replication. The input is a dummy one: you simply type the numbers 1, 2, 3, …, 100 (if you want 100 replications) in the column on the left of the table. Then you specify an arbitrary blank cell in the table to be the column input cell and leave the row input cell blank.

Solver

Excel’s Solver is a tool that allows you to find the optimal solution that satisfies a set of equations and inequalities. If you can describe the behavior of a real system with a set of equations or inequalities in a worksheet, then Solver can help you find the optimal (best) way to operate the system.

If you are interested in the internal workings of Solver you would need to take a course on optimization (for example MATH 373 or MGTSC 701). Or, if you would like to learn on your own then your instructors can provide you with some pointers to good books on the subject.

In MGTSC 352, we will not talk about how solver finds solutions. Instead, we will focus on helping you learn to use Solver as effectively as possible. Below are some tips to help you do that. The reason why the tip makes sense may not always be apparent to you. Unless you are willing to learn how solver works internally, you will have to take those tips on faith.

A solver model has three parts:

- Set cell/Target Cell: A single cell containing a formula. This is the quantity you wish to maximize or minimize. It is sometimes called an 'objective function.'
- Changing Cells/Adjustable Cells: one or more cells that contain numbers. These are the 'decision variables.'
- Constraints: Conditions that the values in the changing cells must satisfy. Constraints are of two types:
    - A formula in one cell is required to be =, ≥, or ≤ a number of formula in another cell.
    - One or more changing cell is required to be integer (a whole number) or binary (either 0 or 1).

Solver can handle four types of models:

		Formulas for set cell and constraints	
		All are linear	Some are nonlinear
Constraints on changing cells	No integer or binary constraints	Linear Programming (LP) problems. These are the easiest and fastest problems for solver to solve.	Nonlinear Programming (NLP). More difficult and take longer to solve than LPs. Solution found may not be globally optimal.
	Some integer or binary constraints	Integer Linear Programming problems. More difficult and take longer to solve than LPs.	Integer Nonlinear Programming problems. The most difficult and time-consuming problems. If solver finds a solution, it may not be globally optimal.

If your problem is linear, you should tell solver, because it will solve more quickly and reliably. How can you tell? You need to check all formulas in your model and make sure they are linear functions of the changing cells. This means that they can only involve addition, subtraction, and multiplication. Furthermore, they can only multiply a changing cell with a constant number. Multiplying two changing cells together makes the formula nonlinear.

See below for how to tell solver your problem is linear.

Frontline Systems (the company that makes solver – www.frontsys.com) sells different versions of Solver. The Solver that Microsoft bundles with Excel is a simpler version of other Solvers that Frontline Systems makes. The Excel Solver allows fewer constraints, is slower, and doesn't perform as well on a class of problems known as non-linear problems. Fortunately, the labs in Business B-24 / B-28 have an upgraded Solver called Premium Solver, which has fewer limitations.

Options in Solver

You can modify several options in Solver and if you do this intelligently it will make Solver run faster and more reliably for you.

- Telling solver your model is linear. Depending on what version of solver you have, this is done either by choosing 'Standard LP/Quadratic' or 'Standard Simplex LP' from a dropdown box in the main Solver dialog box, or by checking 'Assume Linear Model' in the Options dialog box.
- 'Assume non-negative' option. You should always check this option, unless it makes sense for some of your changing cells to have negative values. Older versions of solver do not have this option. If you have an older version, you need to enter non-negativity constraints explicitly. If your changing cells are A1:A10 you would have to include the constraint A1:A10 $\geq$ 0.
- 'Automatic Scaling' option. You should **always** check this option.
- 'Tolerance' (called 'Integer Tolerance' in some versions). This option is only relevant if your model has some integer or binary constraints. Its default value is 0.05 and this means that as soon as solver is convinced that the best solution it has found so far differs by less than 5% from the optimal solution, then it can stop. Set the tolerance to 0 to force solver to keep going until it finds an optimal solution. If this causes solver to run for a long time, then interrupt it (by pressing the 'Esc' key), make the tolerance larger, and try again. Repeat if necessary.
- 'Precision.' Controls how precisely constraints need to be satisfied. For example, if you have a constraint A1 = 10 and the precision is set to be 0.001, then Solver will consider the constraint satisfied as long as the value in A1 is between 9.999 and 10.001. the lower the precision, the more time it will usually take to find a solution.
- 'Max Time' and 'Max Iterations' control how long solver will run. If it reaches one of those bounds before finding an optimal solution it will ask you whether it should continue or stop.
- 'Show iteration results' – do **not** check this option, unless you want to learn how Solver goes from one solution to another in its search for the optimal one. For some problems you will be asked to solver in MGTSC 352, solver may need 100 iterations. If you accidentally check this option when solving such a model, you will need to click 'OK' 100 hundred times before getting to the optimal solution.

Common Problems with Solver

- Not reading what the dialog box says when solver stops. The dialog box always looks the same, regardless of whether it is telling you that it has found the optimal solution, or that no feasible solution exists, or something else. Remember to read what it says.
- Not setting the 'tolerance' to zero for a problem with integer or binary constraints. If you don't, you may not be getting the optimal solution.
- Using IF functions instead of binary variables. IF functions are discontinuous functions, meaning that a small change in the input can cause a large change in output. Solver can only deal with continuous functions.
- Not keeping all parts of your model on one worksheet. All parts of a Solver model must be on the same worksheet. Note that this allows you to have different Solver models in different worksheets.
- Making constraints nonlinear when they don't need to be. For example, if cells A1 and A2 contain formulas that depend on the changing cells, then the constraint A1/A2 ≥ 2 is nonlinear, but it can be replaced by the equivalent linear constraint A1 ≥ 2*A2.
- You know your model is linear, but solver complains that it isn't. Unfortunately, this sometimes happens, because the test Solver uses to check for linearity is not perfect. If this happens, make sure you have checked the 'automatic scaling' option and try again. If that doesn't work, click 'OK' when solver tells you your model is not linear and run solver again. Sometimes, it does not complain the second time (doesn't make much sense, does it? The reason is a bit complicated – see the instructor if you are really curious).
- Paying attention to the 'solution' when Solver says the problem is infeasible, or that the set cell values do not converge. If Solver gives you one of those messages, it is telling you that there is no optimal solution to the problem. The numbers that happen to be in the changing cells when Solver terminates are meaningless in this case.

Visual Basic for Applications

Visual Basic for Applications (VBA) is a programming language that is embedded in Excel and also the other software in the Microsoft Office suite (such as Word, PowerPoint, and Access). Microsoft has also licensed VBA to many other software vendors, allowing them to embed VBA in their own software packages.

VBA allows users to customize Excel by writing small programs called macros. A macro is a series of common actions (keystrokes, mouse movements, etc.), all recorded as one action. For example, you might have a macro that formats a chart exactly as you like it. Another macro might run a simulation a user-determined number of times. A macro could also prompt the user for information, use that information for something, and return the result to the user.

VBA is a relatively easy to use programming language, but it is still quite powerful. Below are several resources that provide more information on how to use VBA.

- MGTSC 422 – a course on simulation that uses VBA.
- “Excel Macros” (http://www.oreilly.com/catalog/exlmacro/) – a book on writing Excel macros in VBA from a top computing science publisher.
- Microsoft’s VBA site (http://msdn.microsoft.com/vba/) – a great starting point for VBA from its creators.
- Anthony’s VBA site (http://www.geocities.com/WallStreet/9245/) – a very useful site with particular emphasis on simulation and financial analysis.