Calculation, Modeling and Simulation

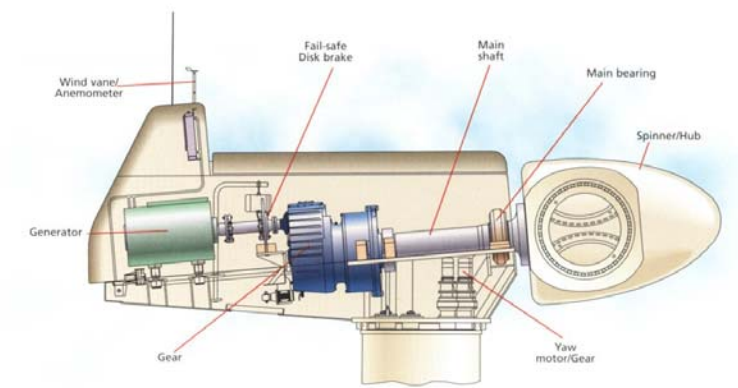
In engineering design, it is essential to estimate, analyze and verify the design before prototype and production are carried out. Thus calculations, modeling and simulations are important steps for a successful design.

Engineering and scientific knowledge and tools are necessary for these calculations, modeling and simulation. The work can be intensive and time-consuming.

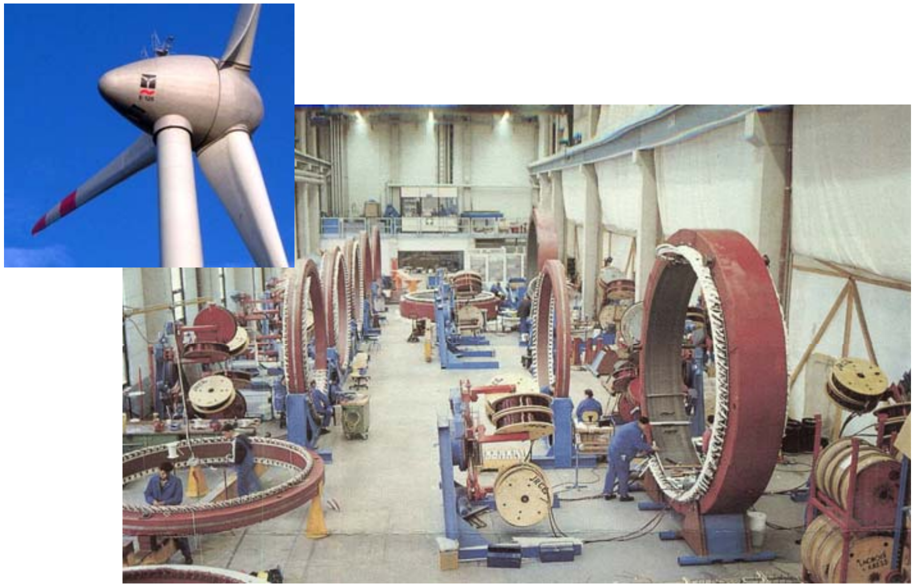
One more example of computer simulation - wind turbine

Converting wind power to electrical power

Generator as a component of a wind turbine - desirable to develop a new direct drive



Large Wind Turbine Generators



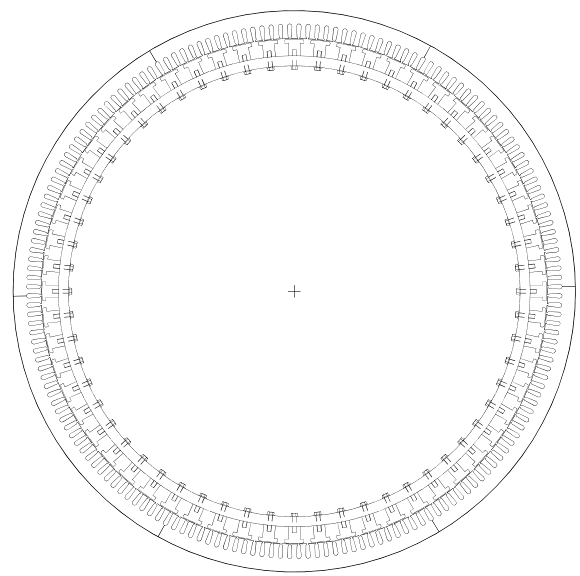
Development of a New Wind Turbine Generator

- Identify the specifications
- Design the generator using empirical method (design based on equations / impirical formulas - similar to your transformer design process)
- Design the generator using finite element method (design and verification based on numerical calculations and simulations)
- Production of prototype generator
- Test the generator for further improvements

Empirical Design - Preliminary

A	B	C	D
DIRECT DRIVE SYNCHRONOUS GENERATOR DESIGN		Design Number One	
SPECIFICATIONS/DESCRIPTIONS	Symbols	Assigned	Calculated
Output Power (watts)	Pout	50000	
Synchronous Speed (Rpm)	RPM	80	
Output Frequyency (Hz)	fout	40	
Line-to-Line voltage (V)	Vline	480	
DC Voltage of the field winding (volts)	Vdc	110	
Number of Phases	m	3	
Power factor	pf	0.97	
Voltage Per Phase (Volts) (Line to neutral)	Vph		277.13
Generator apparant power (VA) =Pout/pf	Sout		51546.39
Generator rated phase (line) current =Sout/3/Vph	Iph		62.00
Insulation		Class F	
Cooling System		Forced Air	
Temperature Rise (Celcius)		70	
ARMATURE DESIGN			
Output constant =(Di*lef*RPM)/Sout in (cm)^3 [Rb]	Cout	433436.15	
Number of Poles	Poles		60
Number of pole pairs	p		30
Airgap Volume=(Di^2*lef) =Sout*Cout/RPM (cm)^3 [Rb]	Avol		279276
lamda=lef/tao=0.8~2 Selected [Ra, Rb]	lamda	3.246	
Inside Diameter of the stator (~airgap dia) (cm) [Rb]	Di		118.00
Effective stator length=Avol/(Di^2) (cm) [Rb]	lef		20.06

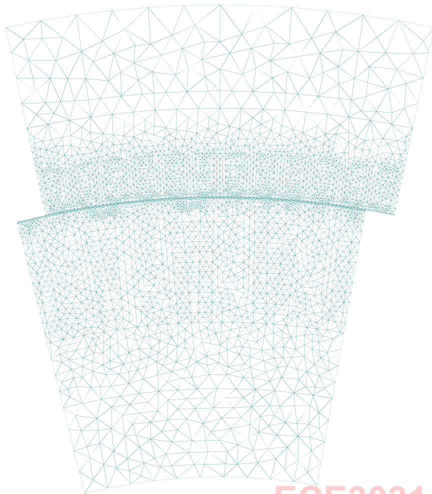
Drawing of the Preliminary Design



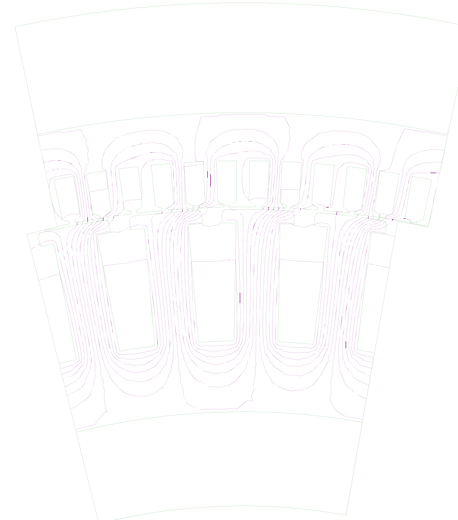
Finite element model: fine-tuning the design -start from physic equations

$$\nabla^2 \underline{A} + \mu\epsilon\omega^2 \underline{A} = -\mu \underline{\boldsymbol{J}}$$

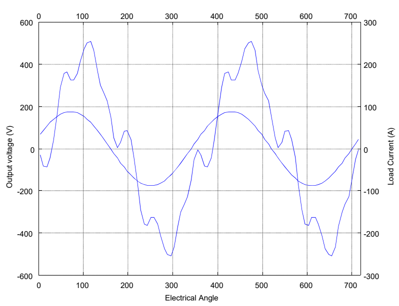
$$\nabla^2 \phi + \mu\epsilon\omega^2 \phi = -\frac{\rho}{\epsilon}$$

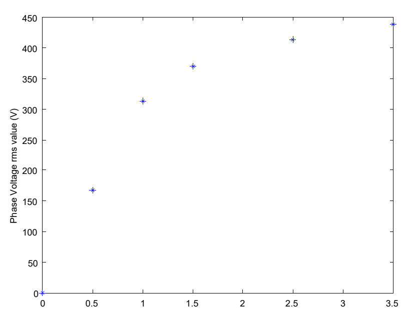


Finite element solutions - magnetic field distribution



Computation of generator characteristics



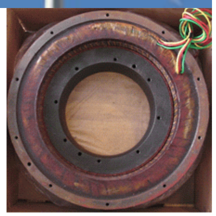


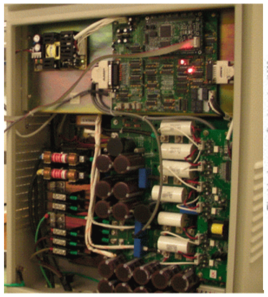
Produce a prototype generator

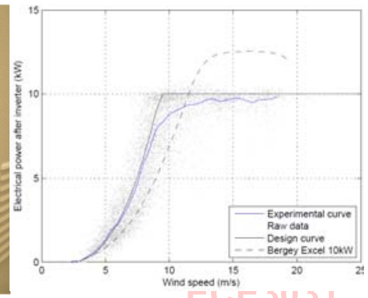
And testing….

WESNet 10kW Small Wind Turbine Demonstration Project

WESNet has developed a complete small wind turbine (10kW) by integrating the innovative technologies developed by multi-university researchers for technology transfer. The turbine system has been in operation in PEI.







Introduction to Modeling and Simulation - a Design Tool

- **What is a model?**
  - **A representation of an object, a system, or an idea in some math or physical forms.**
- **Types of models**
  - **Physical (Scale models, prototypes,…)**
  - **Mathematical (equations, curves, data bases)**
- **Modeling (referred to math. Modeling)**
  - **The process of representing a real-world object, system or phenomenon as a set of mathematical equations that accurately (to a certain degree) reflect the relevant aspects of actual entity. Modeling is an abstraction process that hides the non-relevant details in order to simply study and use of the actual entity.**

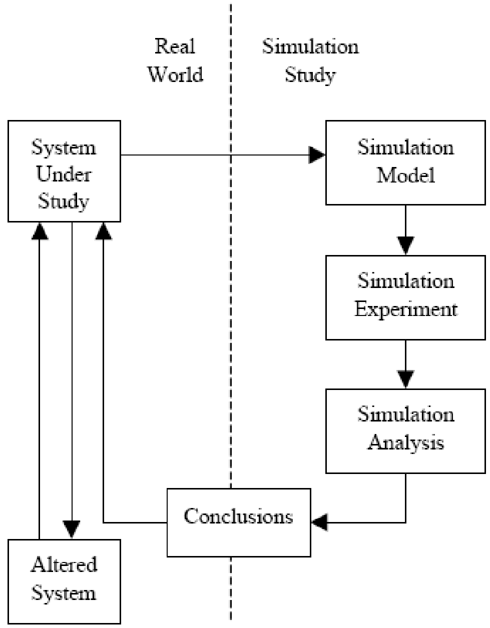
Simulation

- **What is simulation?**
  - **The process of imitating a real system or phenomenon with a set of mathematical formulas and within a certain process of existence. Simulation generally involves the use of models and find the solutions (often numerical solutions) of the models. A major focus is the techniques to correctly interconnect the models and to obtain accurate values (solutions) of the parameters under study.**
- **Purposes and applications of simulation**
  - **To conduct or verify the design**
  - **To understand the behaviors of the system**
  - **To explore alternatives**

Steps in Engineering Modeling and Simulation

- **Identify the problem and objectives**
- **Formulate the problem (with assumptions)**
- **Collect and process real system data**
- **Formulate and develop models (equations)**
- **Select appropriate investigation design**
- **Establish investigation conditions for runs**
- **Perform simulation runs (normally computers)**
- **Interpret and present results (post processing)**
- **Recommend further course of action**
- **Provide sufficient documentation**

Simulation Study in Design



Simulation Tools

- General purpose programming languages
  - FORTRAN, PASCAL, C & C++ etc.
  - Advantages:
    - Low software cost
    - Universally available (portable across platforms)
    - No extensive training
  - Disadvantages:
    - Every model starts from scratch (although there could be library routines available)
    - Very little reusable code for general simulations
    - Long development cycle for each model

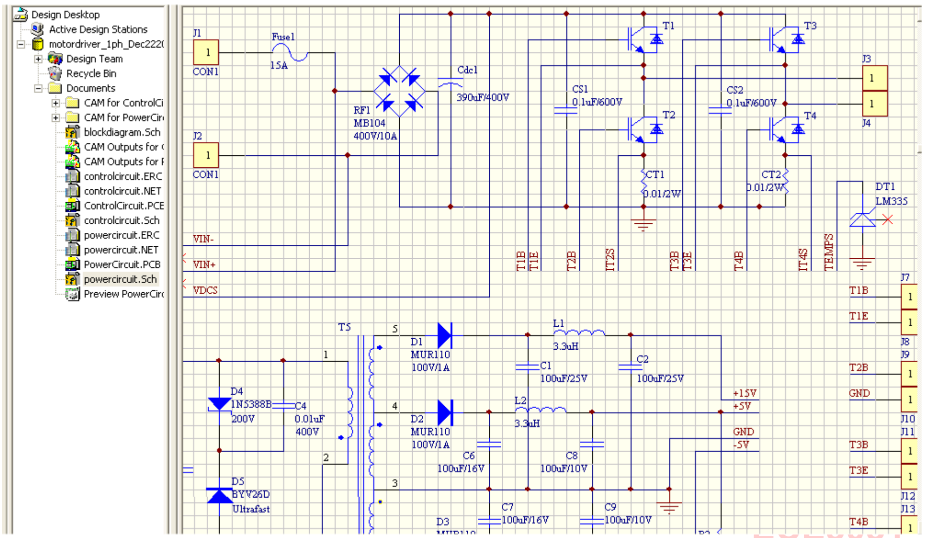
Simulation Tools

- General simulation packages/languages
  - MATLAB, MAPLES, SIMSCRIPT II.5
  - Advantages:
    - Standardized features often available for modeling
    - Shorter development cycle for each model
    - Available assistance in model verification
    - Very readable codes (easy to understand)
  - Disadvantages:
    - Compromised flexibility (models and simulations has to fit the software package)
    - Additional training required
    - Limited portability (models cannot be used for other software packages)

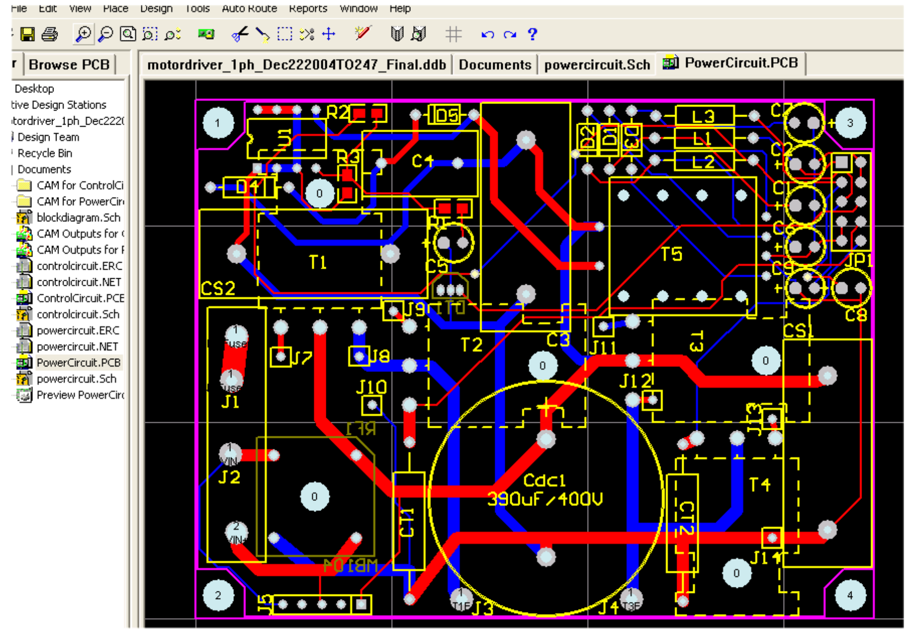
Simulation Tools

- Special simulation packages
  - Finite element package, statistics package, chemical process simulation package, Altium etc.
  - Advantages
    - Quick development of complex & specialized models
    - Relatively short learning cycle
    - Little programming--minimal errors in usage
    - Very specialized expertise imbedded
  - Disadvantages
    - High cost of software
    - Limited scope of applicability (for special purposes)
    - Limited flexibility (may not fit your specific applications), and limited support
    - Need expertise to process the results

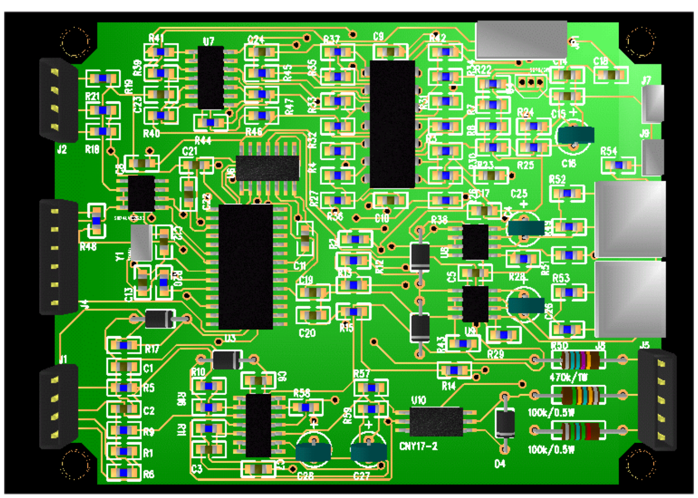
Computer Aided Design for Electrical Circuits



Schematics, PCB and Simulation



a PCB View



Design Optimization

Optimization: to find the extremes of an objective(s) under certain constraints

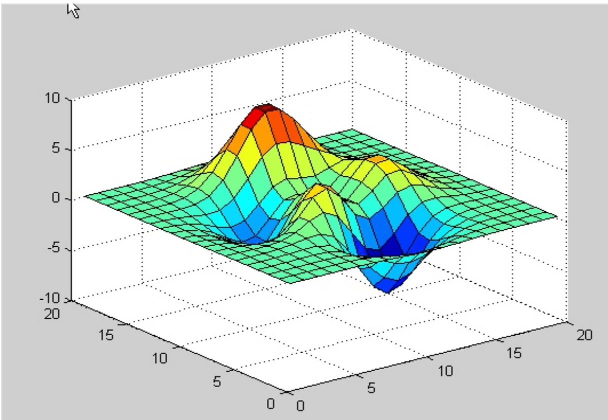
For design problems, many acceptable solutions may exist, and it is up to the designers to seek the best possible solution by taking into consideration the objectives and the associated constraints. The process of determining the best solution is known as optimization.

There are many optimization techniques that give design professionals the capacity to manipulate and refine their work so that the end results are effective and acceptable from all possible directions. Thus, the optimal design may be described as the best of all feasible designs.

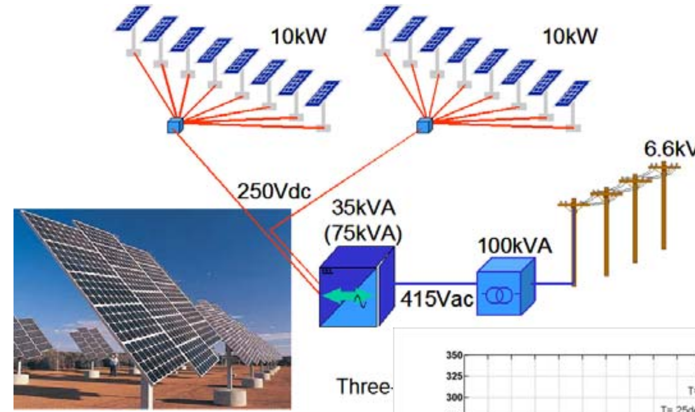
Many Optimization Methods Exist

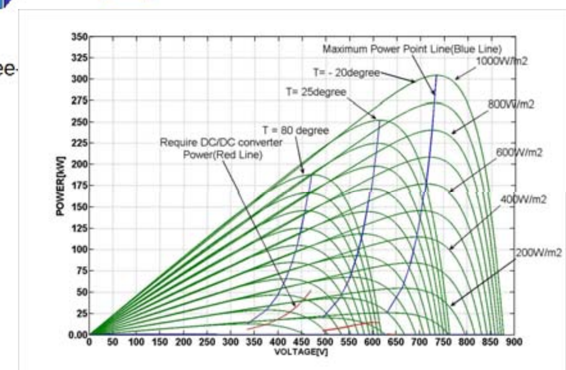
Optimization Method-1: Differentiation

$$\frac{\partial F(y)}{\partial X_1}=0; \quad \frac{\partial F(y)}{\partial X_2}=0; \quad \ldots \quad \frac{\partial F(y)}{\partial X_m}=0$$



A PV System





Optimization Method-2: Linear Programming

Linear programming may be described as a mathematical method of allocating constrained resources to attain an objective, such as to minimize cost or maximize profit. Examples of the resources referred to are: time, labor, material, and money.

3 steps of establishing a linear programming model:

- **Define the associated decision variables**
- **Define the associated objective function**
- **Define the associated constraints**

Then solve the linear programming problem.

Ex: maximize the profit of a shop

Machine Time Needed (3 machines)

	A	B	C	Profit/Unit
Manual stapler (x)	2hr	1hr	1hr	$4
Electric stapler (y)	1hr	2hr	1hr	$6
Hours available	180	160	100 per month	

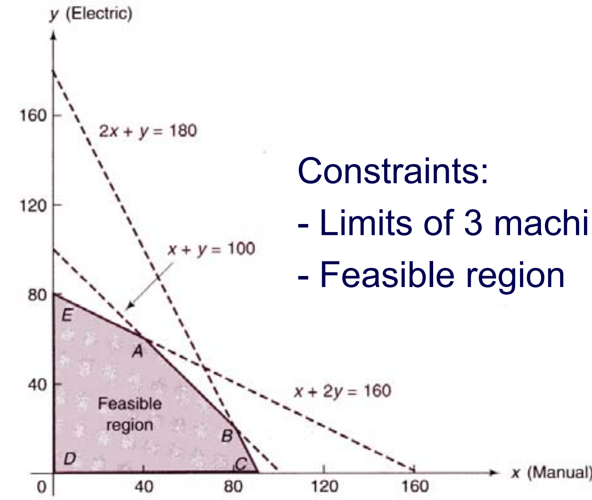
1. Define the associated decision variables:
   x - number of manual staplers produced per month
   y - number of electric staplers produced per month
2. Define the associated objective function:
   profit per month: P=4x+6y

3. Define the associated constraints

$$x \geq 0$$
$$y \geq 0$$
$$2x + y \leq 180 \quad (Machine - A)$$
$$x + 2y \leq 160 \quad (Machine - B)$$
$$x + y \leq 100 \quad (Machine - C)$$

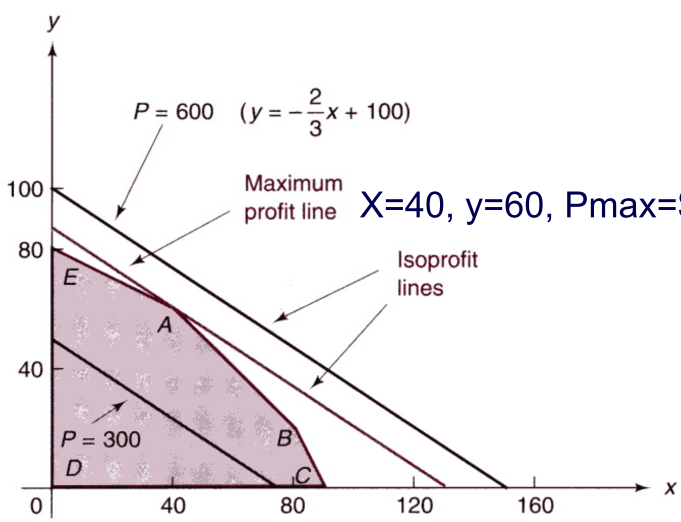
4. Find the solution to the linear programming problem

Feasible Region



Constraints:
- Limits of 3 machines
- Feasible region

Isoprofit Lines and Feasible Region



X=40, y=60, Pmax=$520

Ex: A bit more complex example Maximize the profit/day of the shop

	Manual	Electric Staplers
Profit	\$2	\$5
Constraints	None	Max. 200 per day (parts)
Assembly(45 workers)	18 P-Min	54 P-Min
Adjustment(6 workers)	3 P-Min	5.4 P-Min
Inspection(2 workers)	1 P-Min	1.5 P-Min
Assumed production	Q_M	Q_A (variables)
Profit objective/day	$P=2Q_M + 5Q_A$	
Constraint statements:	?????	

Follow the steps to establish a model

Define variables -quantity: Q_M(manual), Q_A(electric)

Define objective -profit/day: $P=2Q_M + 5Q_A$

Define constraint statements:

$Q_A \le 200$ *(Parts constraints)*

$18Q_M + 54Q_A \le 21600$ *(Assembly constraint: 45*8*60)*

$3Q_M + 5.4Q_A \le 2880$ *(Adjustment constraint: 6*8*60)*

$Q_M + 1.5Q_A \le 960$ *(Inspection constraint: 2*8*60)*

Next: Find the feasible region and find the isoprofit lines graphically;
Identify the maximum profits;

Feasible Region

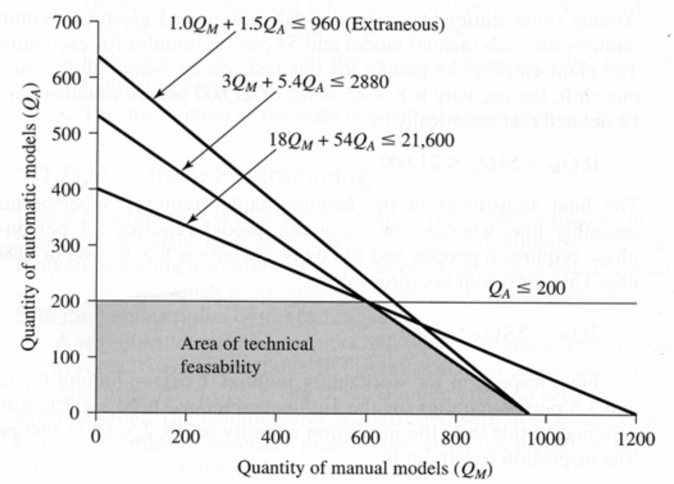


Figure 10.2 Constraints equation without profit.

Isoprofit lines and max. profits

Maximize Profit: $P=2Q_M + 5Q_A$

Best:
Q_M=600
Q_A=200
P=$2200

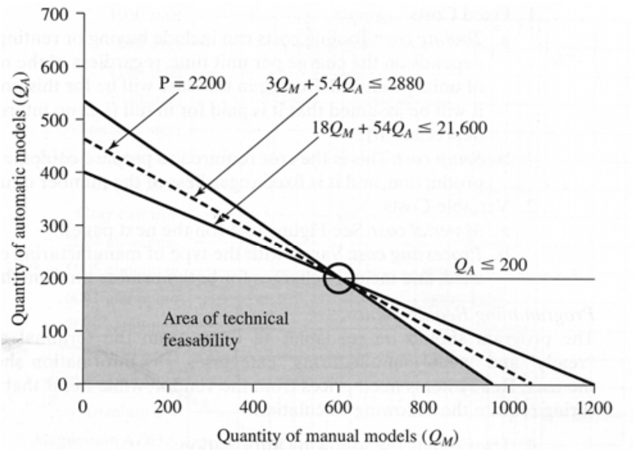


Figure 10.3 Constraints equation with profit.

There are methods to solve linear programming problems mathematically. However, we will not discuss these other methods. We merely introduce the concept of linear programming.

We should know how to establish the model of a linear programming problem and how to solve the problem graphically.