**Synthesis of Ideal Separation Network:**

Separation of multi-component mixtures often requires tasks involving complex schemes. For vapor-liquid mixtures, the complexity of separation is a function of the relative volatility of the constituent species. For zeotropic mixtures, very high product purity can be obtained by employing distillation techniques. For multi-component mixtures, a single cut distillation may produce specified product purity at the expense of a very large number of trays or at a very large value of reflux ratio. Moreover, if the product is of intermediate volatility an almost pure cut of the product in the distillate (or the bottom) is not possible with a single column. This problem can be addressed if the overall complex separation task can be decomposed into simpler tasks. This is possible by having a sequence of distillation operations each producing a cut of lights and heavy compounds. The product of interest can be therefore obtained after a series of column sequences as a heavy cut or a light cut from one of the distillation columns. In this case, the number of separation tasks required to attain a desired level of product purity is solely a function of the volatility of the product species relative to the key components. For products of intermediate volatility and a pure cut of the product in the distillate would entail a total split of all components with volatility higher than that of the product in the distillate. Thus the above mentioned complexity involved with separation of a key product from a multi-component mixture gives rise to the necessity for generating distillation column sequences.

A series of distillation operation task each with a condenser and a reboiler can be generated in a systematic way using the State Task Network (STN) representation of Linninger [1994]. Sequencing of distillation column gives rise to a host of structurally different design solution. For the case of four components there can be five simple distillation column sequences without any side stream product (see Figure below). In general for an N component mixture, in which separation of all pure components are desired, the total number of possible separation sequences attained assuming sharp-split separation is N +1.
The simple column sequences obtained may be sub-optimal due to the large amount of condenser or reboiler duty associated with each of the columns. Therefore a search should be made for column sequences with a fewer number of reboilers and condensers. This gives rise to the scope for partially and fully coupled column sequences. The idea is to systematically eliminate condensers and reboilers from the simple column sequence structure by introducing side cuts. Each of the cuts from the sides can be further sent to different columns. Each simple distillation column operation has a single feed, a distillate and a product. If we consider side stream products from these columns, then the total number of options rises drastically. Each of the side streams when coupled with another distillation column may eliminate the use of a reboiler or a condenser. Thus, by matching streams, the total number of reboiler or condenser duty can be reduced systematically.

Non-Ideal Separation Synthesis:
Synthesis of separation flowsheets for multi-component mixtures often involves dealing with non-idealities like the existence of binary or ternary azeotropes and the liquid phase miscibility gap. The existence of binary or ternary azeotropes in a multi-component mixture induces distillation boundaries, which cannot be overcome by simple separation tasks. Pressure-swing distillation column employs the effect of pressure shifting the distillation region to attain the required separation task. However, high-pressure columns are not common because of the higher operating cost. Moreover, the required pressure may also lead to product degeneration. Hence entrainer based separation techniques are commonly employed to separate multi-component mixtures with azeotropes. Entrainer-based solvent selection requires search for an adequate solvent which is either high-boiling and does not form azeotropes with the key components in the mixture (e.g. extractive distillation) or which selectively forms azeotrope(s) with one or more component in order to facilitate the removal of a solute otherwise not possible due to the separation barrier (e.g. azeotropic distillation).

In non-ideal separation, the product purity cannot be increased indefinitely by increasing the reflux ratio or the number of stages in a distillation column ( unlike ideal separation). The product purity is a function of the separation barrier induced by the different azeotropes in the system. These separation barriers can be identified by studying the Residue Curve Maps (RCM) or the Distillation Region Diagram (DRD). The most challenging task ahead is to define the different distillation regions for a mixture with N-components. This will involves the generation of an N-dimensional residue curve map.