Pavement Performance Prediction Models

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Goals of the NordFoU project – Pavement Performance Models

1. Adopt existing performance/condition prediction models to Nordic conditions and implement improved models in each country.

2. Utilize data from test sections, reference sections, and special equipment in the various countries to evaluate and improve models.

3. Increase competence in the modeling/ calculation of deterioration/condition of road structure in each Nordic country.

4. To disseminate results, information and knowledge in the area of road condition prediction in each Nordic country.

The main project was started in 2007

For information see
http://www.vejdirektoratet.dk/nordisk/aktuelle_projekter.asp

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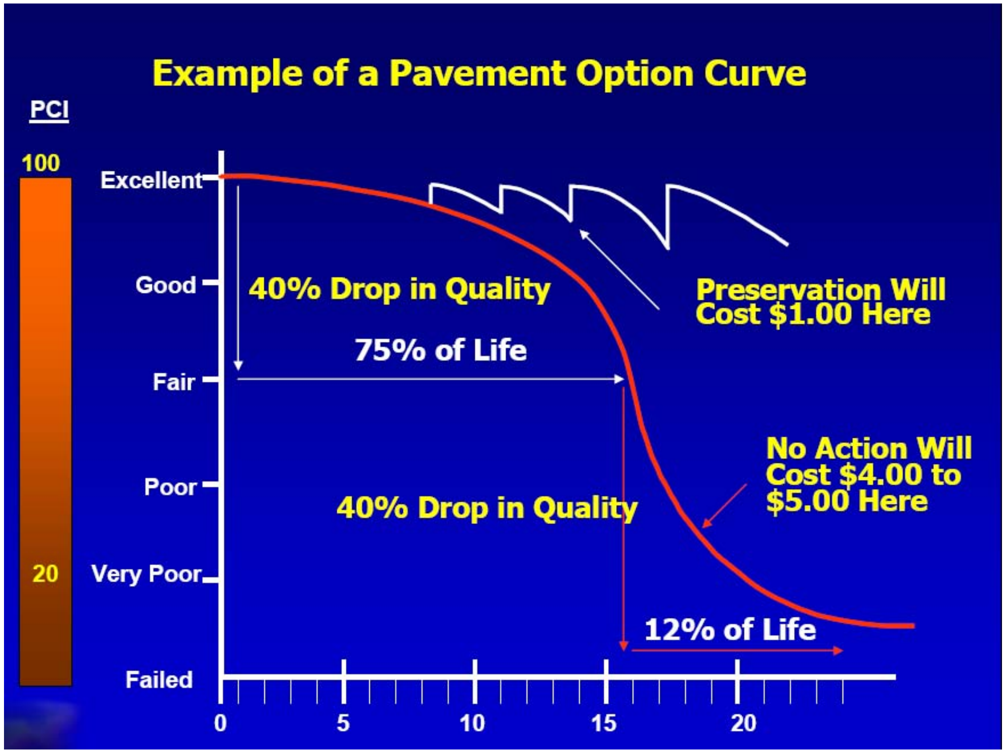
Performance prediction

- Performance/condition prediction is an important element in decision making tools:
  - PMS
  - Asset management systems
  - Design systems
- However it also represents the weakest link in these decision support systems.



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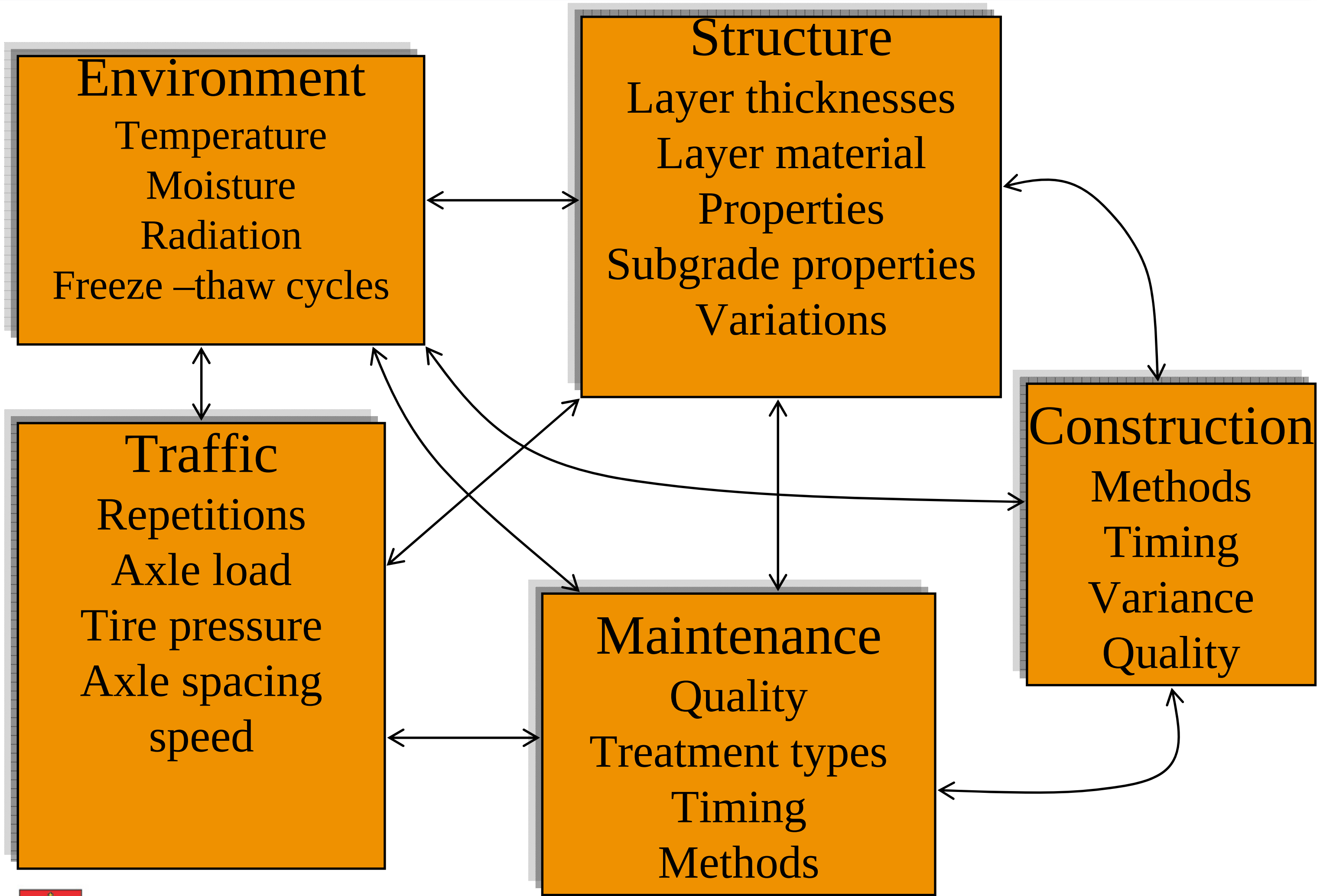
Several factors affect performance



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Available prediction models

- Are not comprehensive enough – simplifications, not all defect types, not all influencing factors, interaction b/n the various defects.
- Accuracy? Not possible to make accurate and precise prediction of pavement life.
- Mostly empirical relationships that can not be applied to other conditions.
- Limitations with regard to:
  - Climatic effects
  - Studded tire effect

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Classes of Performance Prediction Models

- Empirical
- Mechanistic – Empirical
- Probabilistic
- Empirical - Mechanistic

Empirical Performance Prediction Models

- Several empirical equations have been developed.
- Some of them are simple containing just one independent variable (time or traffic).
  - Rut depth = f (axle load repetitions)
- Others are more extensive, containing several variables, eg. HDM -4 models.

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Empirical models: HDM

- Cracking:

$$ICA = K_{cia}\{CDS^2 * a_0 \exp[a_1 SNP + a_2 (YE4/SN^2)] + CRT\}$$

- ICA time to cracking initiation, in years
- CDS construction defects indicator for bituminous surfacings
- SNP structural number of pavement
- YE4 annual number of ESALs, in millions/lane
- K_{cia} calibration factor for cracking initiation
- CRT cracking retardation time due to maintenance

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Empirical models - Limitations

- Developed for use under particular conditions – difficult to use under different conditions.
- Most of them do not contain material properties.
- Are not comprehensive (do not consider all influencing factors).

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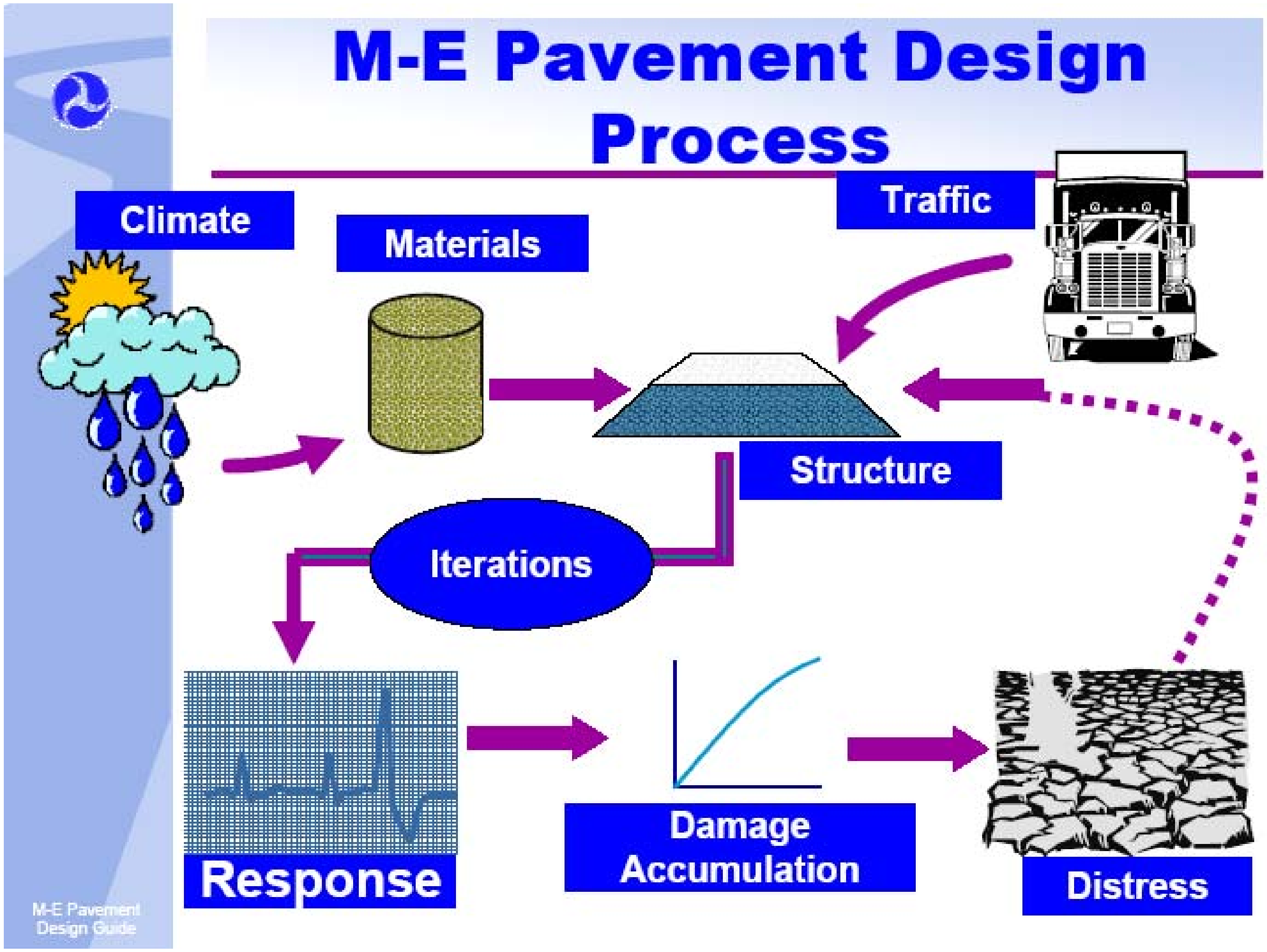
Mechanistic – Empirical models

- Stresses and strains are calculated using the principles of mechanics.
- Material properties are taken into account.
- Effect of climate is considered through its effect on the material properties.
- Empirical transfer functions (that can be calibrated) convert response into damage or performance.
- Example: M-E Design Guide.

M – E design guide



Mechanistic – Empirical example

- ε_p = plastic deformation (rutting) for asphalt layer
- T = temperature, N = no. of load repetitions
- ε_r = resilient strain, E* = dynamic modulus, σ = stresses

$$\frac{\varepsilon_p}{\varepsilon_r} = \beta_{r1} a T^{\beta_{r2} b} N^{\beta_{r3} c}$$

$$\varepsilon_r = \frac{1}{|E^*|}(\sigma_z - \mu\sigma_x - \mu\sigma_y)$$

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Mechanistic- empirical models

- Accuracy depends on both the response models and the performance models.
- Response models contain several simplifications (eg. Material behavior).
- More detailed data input.
- Useful at the project level – for design of the pavement structure.

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Probabilistic models

- Performance of pavements is affected by several factors some of which are difficult to observe/predict.
- Performance varies greatly showing uncertain/random characteristics.
- Further uncertainty arises for measurement/inspection processes.
- Probabilistic models attempt to tackle this stochastic behavior.
- Suited for network level PMS.
- Example: HIPS

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Probabilistic models

$$P(X_{t+1} = j \mid X_t = i)$$

- Mostly based on Markov process modeling.
- P = probability of the state X (pavement condition) being j at time t+1 given that it was i at time t.
- Assumes the probability is independent of time – this is a major limitation.
- Some models attempt to take into account the time dependence.

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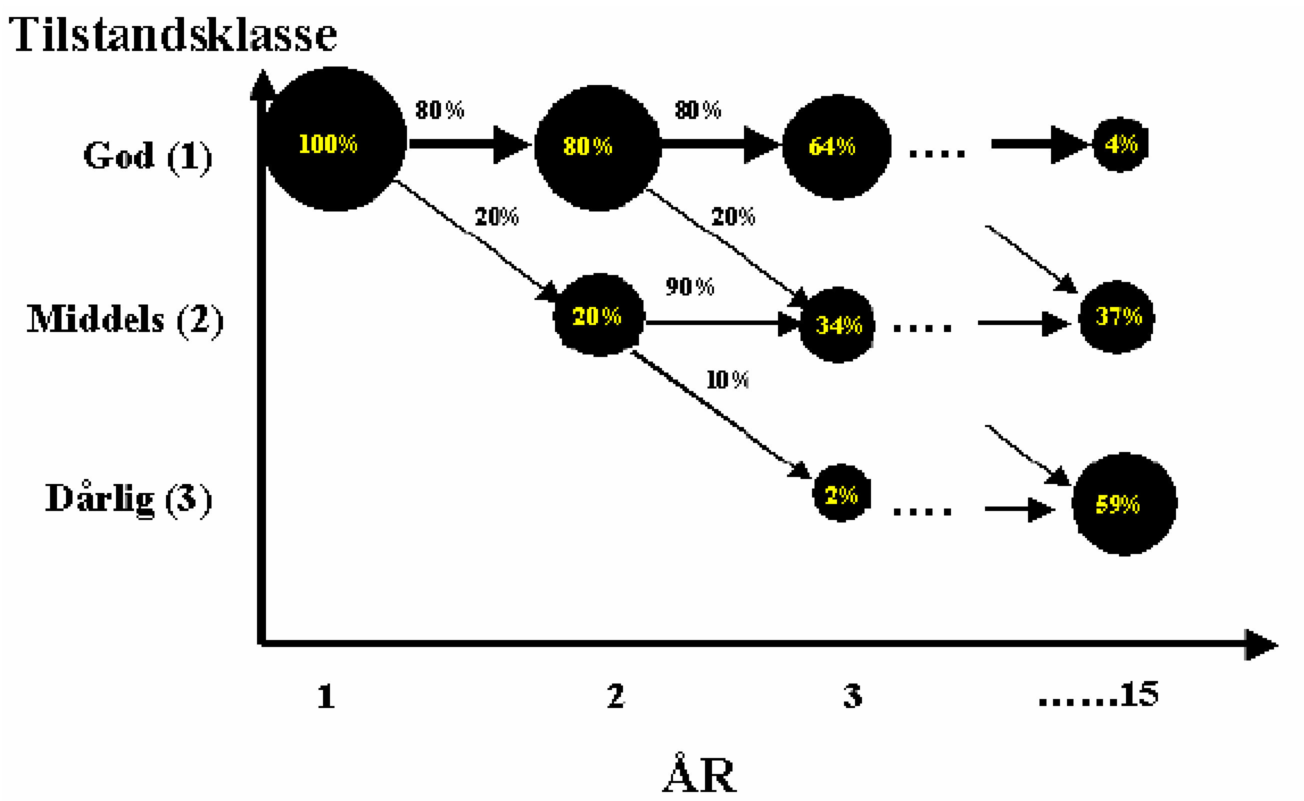
Probabilistic - HIPS

- Divide the network in sub-networks based on road type and ADT
- Choose performance parameters/ indicators
- Number condition classes
- Performance is modelled using probability of condition change from one class to another

Markov chain



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Empirical – Mechanistic models

- Selection of functional form and explanatory variables are based on physical considerations.
- Statistical estimation procedures are used to calibrate models.
- Requires knowledge of relatively small set of variables.
- Suitable for network level PMS.

Empirical - Mechanistic

- T is the time (cumulative ESALs) to cracking
- F(t) = cumulative distribution function
- S(t) = the survival function (probability that cracking occurs after time t)
- g(t) = the probability that the pavement cracks in the next small interval Δt
- h(t) = hazard rate function

$$F(t) = \int_0^t f(s)ds = \mathrm{Prob}(T < t)$$

$$S(t) = 1 - F(t) = \mathrm{Prob}(T > t)$$

$$g(t) = \mathrm{Prob}(t \le T < t + \Delta t \mid T \ge t)$$

$$h(t) = \lim_{\Delta t \to 0} \frac{g(t)}{\Delta t}$$

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Conclusions

- Performance prediction models represent a key element of AMS and PMS.
- Several models have been proposed.
- A Comprehensive model has yet to be developed.
- Many of the models are empirical, developed for application under particular conditions, can not be directly applied under other conditions.
- Empirical, probabilistic, and empirical-mechanistic models are applicable at network level. All need extensive calibration. Mechanistic-empirical models are used for project design.

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Recommendations

- Further development of mechanistic- empirical models are needed: both the response models and performance models need improvement.
- Models should be validated using lager database.
- More work needs to be done to improve the predictive accuracy and capabilities of network level probabilistic and empirical-mechanistic models. Explore ways of improving transition probability matrices by using mechanistic - empirical models.
- Implement existing models.

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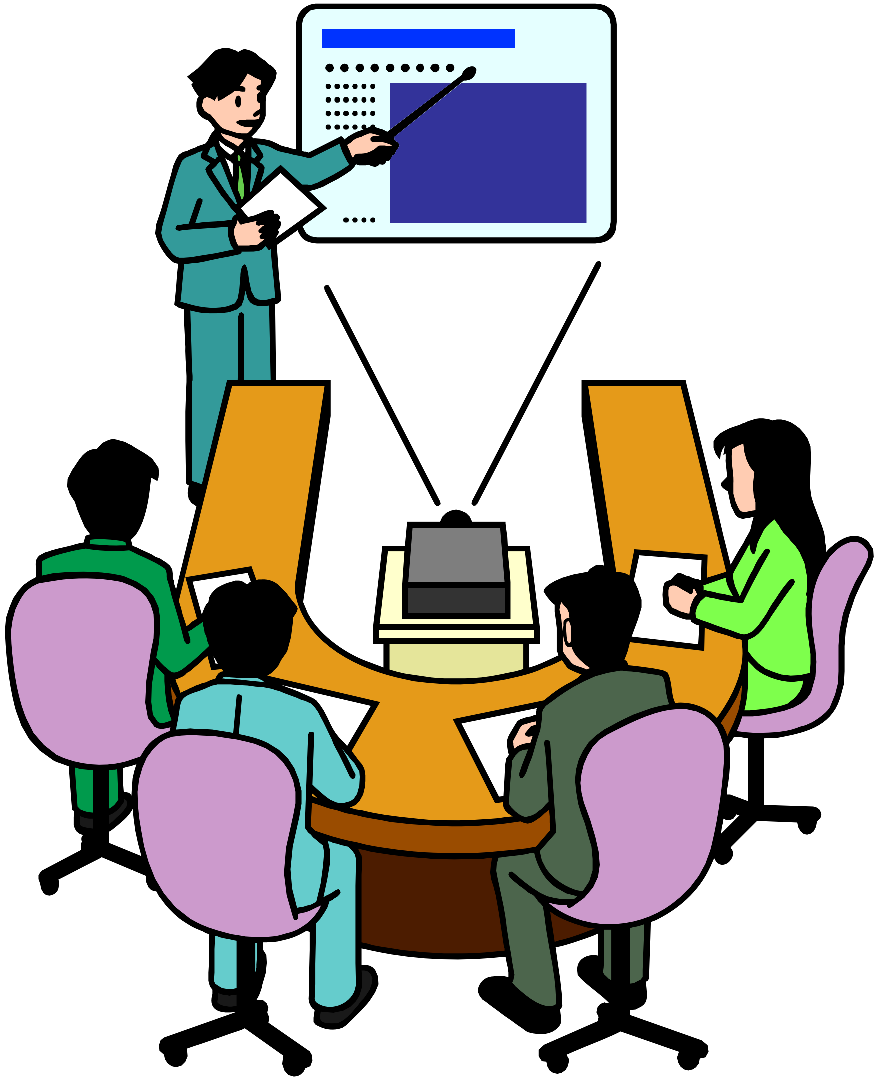
Thank you for attention



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