This document summarizes best practice modelling guidelines for the application of the Simcenter Madymo Active Human Model (AHM). These guidelines consider the following aspects in application of the AHM for automotive occupant safety simulations:

1. *General, integration method & time step, CPU time savers*
2. *Manual pre-positioning*
3. *Muscle & spine control activation*
4. *Contact definitions*
5. *Settling simulation*
6. *Load case simulation*

1. *General settings, integration method & time step, CPU time savers*

Ensure the following fixed, default settings for `SYSTEM.MODEL` for the AHM system (sub-element of `MADYMO`)
- Use `ID = 99` and `NAME = HumanMale50%`

Recommended settings for multibody integration method & time step
- Under `CONTROL_ANALYSIS.TIME` use `INT_MTH = EULER` and `TIME_STEP ≤ 1.0E-05`

CPU time savers for long duration simulations, for example where pre- and in-crash events are combined
- Under `CONTROL_FE_TIME_STEP` use `MIN_STEP` to avoid a too small FE time step (e.g. `MIN_STEP = 1.0E-06`). Use `STATE.FE_MODEL` to keep airbag FE model rigid during pre-crash phase (until airbag triggering)
- Use `STATE.CONTACT` to switch off all airbag related contacts during pre-crash phase (until airbag triggering)
  note: using `MIN_STEP` can introduce FE mass scaling; check your reprint file to ensure the amount of added mass remains small

2. *Manual pre-positioning* (set the AHM in occupant position above the seat - to prepare for an equilibrium simulation)

Either (A) position the complete human model in reference space co-ordinate system:
- Use `INITIAL.JOINT_POS` with `JOINT = Human_jnt` (root joint of the AHM, location is centred between hip joints)
  - use `R3` to set forward facing direction (yaw) aligned with vehicle driving / seat facing direction
  - use `R2` to set pelvis pitch angle in line with seat base inclination
  - use `R1` to set the pelvis roll angle
  - use `D1, D2, D3` to set global longitudinal, lateral, vertical co-ordinates, such that AHM floats above seat surface

Or (B) position the complete human model w.r.t. a local body co-ordinate system of the vehicle or seat model:
- Use `CRDSYS_OBJECT.MB` with `NAME = Human_attachment` (parent co-ordinate system of Human_jnt)
  - use `BODY` and `POS` attributes to attach parent co-ordinate system of AHM root joint to vehicle or seat body
- Use `INITIAL.JOINT_POS` with `JOINT = Human_jnt` to define initial position w.r.t. local body co-ordinate system
  - use `R3` to set forward facing direction aligned with vehicle driving / seat facing direction
  - use `R2` to set pelvis pitch angle in line with seat base inclination
  - use `R1` to set the pelvis roll angle
  - use `D1, D2, D3` to adjust AHM position w.r.t. local body co-ordinate system such that it floats above seat surface

Define the initial posture of the human legs and arms:
- Use the *XMADgic joint positioning tool* (<F11> key) to define initial arm + leg positions (this sets `INITIAL.JOINT_POS` attributes for arm and leg joints (see User Instructions in Simcenter Madymo Human Models manual)

Notes:
A) If modelling an individual or your own population, consider their knee location. Since, a wider gap between the thighs or feet can influence the lateral response similar to that of a stiffer torso.
B) Consider `RESTRAINT.POINT` between the feet (`Calcaneus<L|R>_bod`) and vehicle interior floor (`Vehicle_bod`), with one function for `D1 -D3` with values of `X1 = -0.01, Y1=-250` and `X2 = 0.01, Y2=250`. This will minimise feet translation in a similar way to the behaviour often observed among tested participants.
C) for the spine joints, the `INITIAL.JOINT_POS` values predefined in the user xml-file describe a realistic spine column shape for a relaxed seated person.

3. ***Muscle and spine control activation*** (controller activation procedure when the objective is to maintain the initial AHM posture)

For simulation of living human behaviour, activate AHM joint and muscle control (objective: maintain initial posture):
- Use `DEFINE` elements `Neck|Spine|Hip|Knee|Shoulder|ElbowActivation_def` with `VALUE = 1.0` (range: [0.0-1.0]) to fully activate controllers.
- Use `DEFINE` element `HeadRef_def` with `VALUE = 0` to set controller objective to keep horizontal eye view (VALUE = 1.0 will try to keep to the head aligned with the body specified in `HeadRelBod_def`. For example, to keep the neck fixed, for e.g. roll-over cases)
- Use `DEFINE` element `HeadRelBod_def,` with default set to `VALUE = T1_bod`, to keep the head aligned with a chosen body (e.g. vehicle body for vehicle turn cases)
- Use `DEFINE` elements `NeckCCR_def` with `VALUE = 0.05~0.6` (range: [0.0-1.0]) and `VarNeckCCR_def` with `VALUE = 0` (0 = constant, 1 is variable) to get realistic neck co-contraction behaviour. Co-contraction levels indicate a relaxed (lower Neck_CCR level) or tensed (higher Neck_CCR level) state of the human neck muscles.
- Use `DEFINE` elements `DelayEnable_def` with `VALUE = 1` and `ReactionTime_def` with `VALUE = 0.000~0.160` to set a realistic controller time delay. This time delay applies only to new loading events and is person- as well as situation-dependent.
- Use `DEFINE` elements `StrengthFactor|Global|Neck|Spine|Shoulders|Arms|Legs_def` to adjust model strength. Default setting is `VALUE = 1.0`.

For simulation of post-mortem human subject (PMHS) behaviour, de-activate all AHM joint and muscle control:
- Use `VALUE = 0.0` for all the activations, CCRs and the DelayEnable `DEFINE`s mentioned above.

4. ***Contact definitions***

Contacts with ellipsoid and/or plane seat surfaces
- Use `CONTACT.MB_FE` with `SLAVE_SURFACE = HumanBody_gfe` (complete AHM surface is used)
- Use `CONTACT_FORCE.CHAR` with `CONTACT_TYPE = SLAVE` (assuming seat compliance is modelled in seat joint restraints)
- Use `FRIC_FUNC` to define AHM-seat friction - use function with typical coefficient of 0.3 ~ 0.6, a value of 0.1 has been used for surfaces that are very smooth, rigid, and flat.

Contacts with rigid FE (facet) seat surfaces
- Use `CONTACT.FE_FE` with `SLAVE_SURFACE = HumanBody_gfe` (complete AHM surface is used)
- Use `CONTACT_METHOD.NODE_TO_SURFACE_CHAR` (do not use `GAP_TYPE.*` for characteristic-based contacts)
- Use `CONTACT_FORCE.CHAR` with `CONTACT_TYPE = SLAVE` (assuming seat compliance is modelled in joint restraints)
- Use `FRIC_FUNC` to define AHM-seat friction - use function with typical coefficient of 0.3 ~ 0.6, a value of 0.1 has been used for very rigid and flat surfaces.

Contacts with the FE seat belt (find also predefined in user xml-file)
- Use `CONTACT.FE_FE` with `MASTER_SURFACE = HumanBody_gfe` for contacts with shoulder belt and lap belt
  - the above-mentioned contact groups are recommended to ensure complete body coverage for the belt contacts. To optimise for CPU efficiency, one could consider using `MASTER_SURFACE = Thorax_gfe` for the shoulder belt contact and `MASTER_SURFACE = Thorax_gfe, Pelvis_gfe, Upper_Leg<L|R>_gfe` for the lap belt contact
  - use `CONTACT_METHOD.NODE_TO_SURFACE_CHAR` with `CONTACT_FORCE.CHAR` (do not use `GAP_TYPE.*`)
  - use `CONTACT_FORCE = MASTER` under `CONTACT_FORCE.CHAR`
  - use `ORTHO_FRIC1_FUNC` and `ORTHO_FRIC2_FUNC` for 'belt pocketing' effects through direction-dependent friction
    - typical longitudinal belt friction coefficient: 0.1 ~ 0.3, typical lateral belt friction coefficient: 0.5 ~ 1.0
    - belt meshes generated with XMADgic belt fitter ensure that `ORTHO_FRIC1_FUNC` is for longitudinal direction and `ORTHO_FRIC2_FUNC` is for lateral direction
- To avoid the seat belt penetrating too deep into the human skin surface it is recommended to also define contacts with some of the underlying bone surfaces:
  - for the shoulder belt, use `CONTACT.FE_FE` with `MASTER_SURFACE = ShoulderBones<L|R>_gfe`
  - for the lap belt, use `CONTACT.FE_FE` with `MASTER_SURFACE = IliacWings_gfe`

- for these contacts use `CONTACT_METHOD.SURFACE_TO_SURFACE` with `CONTACT_FORCE.ADAPTIVE`, using `CONTACT.EDGE GAP_TYPE.FUNC` with a 1mm gap function

5. **Settling simulation** (settle AHM into a seated equilibrium position)

- Define a gravity field using `LOAD.SYSTEM_ACC` with `SYSTEM_LIST = ALL` (or include at least the AHM system)
  - use `AZ_FUNC` to refer to gravity function (x-range covering simulation time, constant y-value -9.81 m/s^2)
- Lock AHM leg bone deformation (bending/fracture) joints and make all AHM deformable bodies rigid
  - enable predefined `STATE.JOINT`, `STATE.BODY` and `SWITCH.TIME` elements under `DISABLE` in AHM user xml-file
  - for driver applications (hands on steering wheel) lock the `RadioUlnaris<L|R>_jnt` and `Wrist<L|R>_jnt` joints
- Set the `DEFINE`s `Neck|SpineActivation_def` to `VALUE = 1` and other activation `DEFINE`s to zero and disable the time delay:
  - for `DelayEnable_def` use `VALUE = 0`, this will maximize the speed of the settling process
- Define joint position output for AHM positioning joints
  - enable predefined `OUTPUT_JOINT_DOF` element under `DISABLE` in AHM user xml-file
- Disable hysteresis by `HYSTERESIS_IGNORE = ON` defined under `CONTROL.OUTPUT` for all characteristics in model to ensure proper equilibrium for the load case simulation.
- For simulation of driver load cases, define a `RESTRAINT.POINT` between each hand and the steering wheel.
- For simulation of passenger load cases, position the hands via the shoulder, elbow and wrist joints to have them resting on the lap (upper legs) or seat cushion (aside upper legs). `RESTRAINT.POINT` can be used to support the hands to maintain the defined posture.
- Apply a run time of at least 0.5 second to allow the model to reach proper equilibrium (depending on the starting position)
  - Settling simulation output provides, joint position degrees of freedom versus time in an output (*.jps file or *.h5 file) file. The values from the last time step provide the AHM position in equilibrium state.
  - Settling simulation output provides, muscle and actuator controller activation level versus time in an output (*.control) file. The values from the last time step provide the AHM controller activation levels in equilibrium state.

6. **Load case simulations**
- Import initial joint positions for the AHM from the *.jps / *.h5 file output from the settling simulation into the load case simulation model. Importing can be done using XMADgic ('Tools' – 'Active Human Initialiser')
- Import initial AHM controller activation levels from the *.control file output of the settling simulation into the load case simulation model. Importing can be done using XMADgic ('Tools' – 'Active Human Initialiser') (XMADgic v7.8 and higher)
- Maintain AHM - seat contact definition settings (see section 4) as defined in the settling simulation.
- For seat belt fitting, the XMADgic belt fitting wizard can be used (<F10> key). For shoulder belt fitting, select `Thorax_gfe` under 'Groups' for AHM surfaces, for lap belt fitting, select `BodyNoArms_gfe` or `Thorax_gfe` + `Pelvis_gfe` + `Upper_Leg<L|R>_gfe`. No gap needs to be defined for belt fitting with the XMADgic wizard.
- Define AHM - seat belt contact definitions as specified under section 4.
- Define AHM – airbag contacts and other AHM – vehicle interior contacts where applicable.
- For simulation of driver load cases, define a `RESTRAINT.POINT` between each hand and the steering wheel, combined with a `STATE.RESTRAINT_REMOVE` with a `SWITCH.SENSOR` releasing the hands at e.g. 300 - 500 N.
- For simulation of passenger load cases, position the hands via the shoulder, elbow and wrist joints to have them resting on the lap (upper legs).
- For occupant load cases with no roll-over involved, use `DEFINE` element `HeadRef_def` with `VALUE = 0` to set controller objective to keeping the eye view horizontal.
- For occupant load cases with roll-over involved, use `DEFINE` element `HeadRef_def` with `VALUE = 1` to set the controller objective to keeping the head aligned with T1 vertebra i.e. keep the neck fixed. Use `DEFINE` element `HeadRelBod_def` to align the head to a body of choice other than the default `T1_bod` (e.g. `Vehicle_bod`).
- To simulate a voluntary movement or reflex motion, define for all degrees of freedom of the neck, elbow, hip, and knee, a `FUNCTION.XY` "`*_target_fun`" in the user file. By default, these are constant zero, setting

controllers objective to maintain the initial AHM position. The function value is the angle relative to the initial conditions and therefore, for a smooth motion the functions should start at zero.

- Apply integration method and time step settings according to section 1, of these guidelines, to run load case simulation.
- If modifying a settling run to a full simulation, set **DEFINE**s **Shoulder|Elbow|Hip|KneeActivation_def** and **DelayEnable_def value** = 1