Sample Scenario Development: Heart Failure

Goal: Develop a scenario for a patient in Heart Failure.

Target beginning vital signs:
HR: 118 bpm BP: 160/100 mmHg RR: 32, labored SpO_2: 84%

Target endpoint after treatment:
HR: 110 bpm BP: 140/85 mmHg RR: 18, non-labored SpO_2: 97%

Step 1: Open and connect 'Standard Man'. (This is the recommended starting point).

Note: For this scenario development exercise, we will start with Standard Man and then modify the physiology (patient parameters) in the first state (Baseline/Setup) to reach a new baseline physiology for our *Heart Failure* patient. For some simulator exercises we may wish to start with a pre-existing patient (e.g. Truck Driver or Standard Granny) for simplicity or to save time.

We could also save our changes as a new patient (e.g. Mr. Heart Failure), thereby eliminating the need to setup the patient's presenting physiology in the baseline state. (See the **HPS User Guide, Rev. 4, Section 5, pages 5.43 to 5.47** or the **ECS User Guide, Rev. 6, Section 7** for details on editing and saving custom patients).

Step 2: Open the 'Scenario Editor', add five (5) *New State* entries:

Baseline/Setup
Initial Assessment
Condition Worsens Before Treatment
Slight Improvement After Lasix
Continued Improvement

The state names are taken from the Scenario Development Form (*Scenario Develop Form – Heart Failure*), which details the clinical course for the scenario. (See the **HPS User Guide, Rev. 4, pages 6.19 – 6.62** or the **ECS User Guide, Rev. 6, pages 6.19 to 6.62** for details on using the Scenario Editor).

Step 3: Turn on the *Recorder*

The recorder captures all parameter adjustments that are made as the scenario is developed and edited. When a desired state target point is achieved, the relevant parameters are *dragged* to the appropriate state within the scenario.

Step 4: Adjust *Respiratory Parameters* to obtain the target respiratory values.

When developing patients or scenarios involving respiratory *and* cardiovascular changes, it is recommended that one first make changes to the respiratory parameters then the cardiovascular parameters. If you adjust the cardiovascular parameters first and then the respiratory parameters you will probably have to make several adjustments of the cardiovascular parameters after setting the respiratory parameters because of the link between the cardiovascular and respiratory models. Following the recommended procedure (respiratory first then cardiovascular) often reduces the need to repeatedly 'tweak' parameters.

For example, if we want a patient or state with elevated heart rate and low PaO_2, we may arrive at the desired endpoint (e.g. HR = 90, PaO_2 = 65) simply by increasing the shunt fraction (respiratory parameter). With the modeling link between respiratory and cardiovascular systems, as the supply of oxygen falls (PaO_2 declines) the heart rate automatically increases in an attempt to maintain a relatively constant oxygen supply to the tissues. If we had first raised the heart rate and then increased the shunt fraction chances are we would overshoot the desired heart rate when the respiratory system is adjusted, thereby making it necessary to 'tweak' the heart rate.

Step 5: Increase the patient's oxygen consumption

Our patient in this scenario weighs 100 kg so it reasonable to increase the oxygen consumption from 200 ml/min (default, Standard Man) to 300 ml/min. Use the *Oxygen Consumption* parameter to set the consumption to the higher value.

Step 6: Set the SpO_2 close to the target value using the '*Shunt Fraction*'.

Our target SpO_2 is 84% which corresponds to a PaO_2 of approximately 50 mmHg. Typically, shunt fraction values of 0.10 to 0.40 are needed to create large alveolar-arterial oxygen gradients sufficient to cause arterial hypoxemia. This is because as the shunt fraction is increased, the respiratory controls increase the patient's respiratory rate and tidal volume in an attempt to maintain adequate arterial oxygenation.

Setting the shunt fraction (**SF**) to 0.25 gives a SpO_2 value of 93%, too high. (**Note:** It is important to allow enough time for the PaO_2 to stabilize following changes to the respiratory parameters. Watch the PaO_2 values on the HUD and when the value shows minimal change then steady-state has been reached).

Increasing the **SF** to 0.35 gives a SpO_2 value of 88% which is still too high. A **SF** of 0.45 brings us close to our target SpO_2 of 84%.

Step 7: Set the respiratory rate using the '*Respiratory Rate Factor*'.

With the completion of *Step 6* the respiratory rate has already shown an increase in response to the falling SpO_2, and it is close to our desired initial respiration value of 32 breathes per minute. Increasing the respiratory rate factor (**RRF**) to 1.40 brings us to our target point.

Note: Instead of raising the **RRF** we could have lowered the tidal volume factor (**TVF**). Doing so would result in a respiratory cycle with reduced tidal volumes and, subsequently, a higher respiratory rate as the models attempt to maintain adequate oxygenation. Generally, however, one first adjusts the **RRF** unless the resultant tidal volume is too large (or small) for the clinical condition.

Step 8: Set the '*Baroreceptor Gain (overall) Factor*' to 0.0.

The baroreceptor gain factor determines how vigorously the patient responds to changes in the mean arterial pressure (MAP). Setting the baroreceptor gain (overall) factor to 0 "breaks the link" between blood pressure and the cardiovascular controls that attempt to keep the patient at their baseline MAP. With the gain set to 0, one can independently adjust the heart rate or blood pressure with limited "cross talk" between the two parameters.

Step 9: Set the heart rate to the target value using the '*Heart Rate Factor'* and adjunct the '*Ischemic Index Sensitivity.'*

Our target rate is 118 bpm or approximately a 70% increase in heart rate. However, after the earlier respiratory and cardiovascular changes, the heart rate has already increased. Therefore, we do not need to raise the heart rate factor (**HRF**) by 70% but, rather, a smaller increase, maybe 20 to 30%.

Setting the **HRF** to 1.3 (30% above the default value of 1.0) results in a heart rate of 134, this is too high. Setting the **HRF** to 1.20 gives our patient a heart rate of 120; this is close to our target.

Note: If you adjust the blood pressure first and then the heart rate you will probably have to 'fine tune' the blood pressure after setting the heart rate. This is because the blood pressure is always "sensitive" to heart rate fluctuations even when the baroreceptor gain is set to 0.

Since our patient is hypertensive, tachycardic, and tachypnic it is necessary to make him less sensitive to ischemic changes so as to prevent the death spiral. Thus set the **Ischemic Index Sensitivity** to 0.10.

Step 10: Set the blood pressure to the target value using the '*Resistance Factor: Systemic Vascular*' and the '*Venous Capacity Factor*'.

Our target is 160/100 mmHg so we want to increase the systemic vascular resistance and decrease the venous capacitance. In essence, we want to decrease the amount of blood on the venous side of the cardiovascular system, "shift" it to the arterial side and increase the pressure on this greater arterial fluid volume.

Setting the systemic vascular resistance factor (**SVRF**) to 2.0 and the venous capacity factor (**VCF**) to 0.5 results in a blood pressure that is too high. We have 'moved' too much blood to the arterial side and applied too much pressure to the arterial vessels. Reducing the **SVRF** to 1.5 results in a pressure of approximately 160/98, which is pretty close to our target.

Note 1: It is not necessary to always change both **SVRF** <u>and</u> **VCF**. When 'fine tuning', changes in one or the other may suffice. The **SVRF** tends to change systolic blood pressure while **VCF** tends to change diastolic blood pressure.

Note 2: To raise the blood pressure 'on the fly' (e.g. an anxious patient), raise the **SVRF** and/or lower the **VCF**.

Step 11: Note the patient's new mean arterial pressure (MAP) displayed on the HUD.

Following the above parameter changes, our patient's MAP is now approximately 128 mmHg. This will be the new target control pressure.

Step 12: Set the '*Baroreceptor Maximum Pressure*' and the '*Baroreceptor Minimum Pressure*'.

The 'baroreceptor control mechanism' attempts to maintain the mean arterial pressure (MAP) at a value halfway between the baroreceptor minimum pressure and baroreceptor maximum pressure. Typically, the 'maximum' and 'minimum' pressures are set 20-30 mmHg above and below the MAP, respectively.

For our patient, the new 'maximum' pressure is 128 + 20 or 148 mmHg and the 'minimum' pressure is 128 – 20 or 108 mmHg.

Note: For 'Standard Man' the baroreceptor maximum and minimum pressures are 'hard-wired' into the patient's control parameters. In other words, Standard Man uses maximum and minimum values that are set within the HPS code and the patient 'ignores' the values presented on the user interface.

Step 13: Set the appropriate discrete parameters for the Baseline state.

Our patient weighs 100kg so set the *Patient Weight* to 100.0

Our patient presents with "wet" breath sounds so set the *Breath Sounds* to Rales.

We have also stipulated that the pedal pulses are absent. Therefore, set both *Popliteal/Pedal Pulses* to 'Off'.

Step 14: Transfer the modified parameters from the *Recorder* to the 'Baseline/Setup' state.

Working from the bottom of the Recorder list, move the last (or only) occurrence of each parameter to the 'Baseline/Setup' state. The order of the parameters generally does not matter, though it is often easier for troubleshooting or additional editing if similar parameters (e.g. cardiovascular, respiratory) are grouped together.

Double-check that all relevant parameter changes are incorporated into the 'Baseline/Setup' state of the scenario.

Step 15: Add 'Onsets' for parameter changes, where appropriate. **(Optional)**

For numerical (quantitative) parameters an onset time allows for a smooth setup of the patient's physiology when changing from one parameter setting to another.

For example, if the heart rate factor is changed from 1.0 to 1.5 and this happens instantaneously then the vital signs (as displayed on the patient monitors) will show abrupt changes. This often distracts from the learning objective. Therefore, it is recommended that onset times are used.

In the initial, first state, a relatively short onset time (e.g. 15 seconds) will suffice. For future states, longer onset times (e.g. 1-2 minutes) are often used to allow for a smooth, gradual change in vital signs.

Onsets should not be used with discrete parameters (e.g. breath sounds, pedal pulses) as odd or unexpected changes may occur.

Step 16: Delete the parameter changes from the Recorder.

After the appropriate parameter changes are incorporated into the current state (in this case the Baseline/Setup state) delete the Recorder list to avoid confusion when making parameter changes for other states.

SYNOPSIS OF THE SCENARIO DEVELOPMENT TO THIS POINT:

In Steps 1-12 we modified selected respiratory and cardiovascular parameters in order to develop our *Heart Failure* patient. We used Standard Man's baseline physiology as our starting point and made adjustments to obtain our target patient status as defined in the clinical course of our scenario (Baseline state).

Our target vital signs were:
HR: 118 bpm   BP: 160/100 mmHg   RR: 32 breaths/min SpO_2: 84%

In Step 13 we added any discrete changes (e.g. Breath Sounds to Rales, Patient Weight to 100 kg).

In Step 14 we then transferred from the Recorder to the first state (Baseline/Setup) the modified parameters that now define our "baseline" patient.

In Step 15, we added onsets to the cardiovascular and respiratory changes to allow for a smooth change during setup (optional).

In Step 16 we deleted the changes from the Recorder after the appropriate parameter adjustments were transferred to the scenario. This aids in preventing confusion when developing later states within the scenario.

We then transferred the following thirteen (13) parameters from the Recorder to our 'Baseline/Setup' state:

Set <u>Oxygen Consumption</u> **to** 300.0
Set <u>Shunt Fraction</u> **to** 0.45 **over** 15 seconds

Set Respiratory Rate Factor **to** 1.20 **over** 15 seconds
Set Baroreceptor Gain (overall) Factor **to** 0.0
Set Heart Rate Factor **to** 1.20 **over** 15 seconds
Set Ischemic Index Sensitivity **to** 0.10
Set Resistance Factor: Systemic Vasculature **to** 1.5 **over** 15 seconds
Set Venous Capacity Factor **to** 0.5 **over** 15 seconds
Set Baroreceptor Maximum Pressure **to** 148.0
Set Baroreceptor Minimum Pressure **to** 108.0
Set Patient Weight **to** 100.0
Set Breath Sounds **to** Rales
Set Left Pedal Pulse **to** Off
Set Right Pedal Pulse **to** Off

After moving the parameters to the Baseline state we cleared the Recorder of the changes we made.

We will then continue with the Scenario Development for the remaining states following the principles outlined above and based on our target values as defined in the 'Scenario Develop Form – Heart Failure' document.

The changes to consider for the remaining states are as follows:

For State 2, 'Initial Assessment', we need to re-establish the baroreceptor link.

In the 'Baseline/Setup' we turned off the baroreceptor controls to allow our blood pressure and heart rate to both increase towards our target values.

1. To re-establish the link between MAP and the baroreceptor response (i.e. heart rate increase/decrease, systemic vascular resistance increase/decrease, etc.) the baroreceptor controls must be 'turned on'. A setting of 1.0 gives a normal response to MAP changes, a setting of less than 1.0 gives a blunted response, while values above 1.0 result in a more vigorous response to MAP changes.

2. If we anticipate that the scenario will raise the blood pressure and the heart rate, it may be helpful to blunt the baroreceptor response (i.e. set the baroreceptor gain (overall) factor < 1). A setting of <1 allows the blood pressure and heart rate to both rise.

3. For this particular scenario, set the '*Baroreceptor Gain (overall) Factor*' to 1.0

Note: We could not have turned the baroreceptor controls back on in the first state, 'Baseline/Setup' because the command to turn off the controls would have conflicted with the command to turn the controls back on. In other words, the command '**Set** Baroreceptor Gain (overall) Factor **to** 0.0' would have conflicted with the command '**Set** Baroreceptor Gain (overall) Factor **to** 1.0'.

These two instructions can not appear in the same state. If they did, one or the other, but not both, would be activated.

Adding a transition:

As stipulated in our scenario development document, we will include an automatic transition from the 'Baseline/Setup' state to the 'Initial Assessment' state. When the scenario enters the 'Initial Assessment' state the instructor knows that the simulated patient is set for student assessment, i.e. the cardiovascular and respiratory parameters have reached their target values.

1. Add a transition from the 'Baseline/Setup' state to 'Initial Assessment':

    If Time in State **>** 30 seconds **then go to** *Initial_Assessment*

Note: Some respiratory vital signs (e.g. respiratory rate, SpO2) may change slightly in the 'Initial Assessment' state. This is because the respiratory changes implemented in the 'Baseline/Setup' state may not yet have reached steady-state conditions. If this is problem then increase the transition time between 'Baseline/Setup' and 'Initial Assessment'.

For State 3, '*Condition Worsens Before Treatment*':

Our target vital signs are:
HR: 136 bpm BP: 162/118 mmHg RR: 32 breaths/min SpO_2: 91%

Note: For State 3, remember that the scenario calls for supplemental oxygen (2LPM nasal cannula). Therefore, it is important to apply 2LPM of O_2 when implementing the parameter changes for State 3.

ECS Customers: Use the *"Fraction of Inspired Oxygen Override"* (Tabs/Respiratory/Lung) to simulate the application of supplemental oxygen via nasal cannula. Use a setting of 30% for 2LPM.

1. To improve the oxygenation, (SpO_2) decrease the *Shunt Fraction*. Try lowering the shunt fraction first to 0.40. Remember to allow sufficient time for each change to stabilize.

2. To reach our target heart rate of 143, increase the *heart rate factor*. A value of 1.65 will probably work well.

3. In State 3 the systolic pressure is approximately the same as in the *Initial Assessment* state. However our target diastolic pressure has increased from 100 to 118. In other words, there is a narrowing of the pulse pressure.

    The elastance parameters are used to adjust the systemic pulse pressure. In the HPS system *Elastance: Extrathoracic Arteries* and *Elastance: Intrathoracic Arteries* are used to adjust the elastance of the extrathoracic and intrathoracic arteries, respectively. An increase in the elastance value results in a wider pulse pressure. Generally, both parameters should be altered in the same direction, i.e. both parameters should either be increased or decreased.

For Standard Man, the default values are 1.1 mmHg/ml and 2.8 mmHg/ml, extrathoracic and intrathoracic elastance, respectively. These settings yield a pulse pressure of approximately 65 mmHg (SBP – DBP). In State 2, we want our pulse pressure at roughly 44 mmHg, a decrease in the pulse pressure. Therefore, we want to *decrease* the elastance values.

Settings of 0.9 (extrathoracic elastance) and 2.4 (intrathoracic elastance) should bring us close to our target pulse pressure.

After doing this you will note our blood pressure needs further adjustment. Increase the SVRF to 2.0 to achieve our desired blood pressure of 156/116, close to our target.

4. Once the target endpoint is reached, transfer the appropriate parameter changes to State 3, 'Condition Worsens Before Treatment' of the Heart Failure scenario.

5. Add an *Onset* to each parameter change to allow for a smooth change in patient vital signs. A value of 1 to 2 minutes will work well.

For State 4, '*Slight Improvement After Lasix*':

Our target vital signs are:

HR: 130 bpm BP: 150/102 mmHg RR: 24 breaths/min SpO_2: 96%

Note: For State 4, remember that the scenario calls for supplemental oxygen (4LPM nasal cannula). Therefore, it is important to apply 4LPM of O_2 when implementing the parameter changes for State 4.

ECS Customers: Use the *"Fraction of Inspired Oxygen Override"* (Tabs/Respiratory/Lung) to simulate the application of supplemental oxygen via nasal cannula. Use a setting of 42% for 4LPM.

1. To improve the oxygenation, (SpO_2) decrease the *Shunt Fraction*. Try lowering the shunt fraction first to 0.25 then, if necessary, to 0.20. Remember to allow sufficient time for each change to stabilize.

2. The *respiratory rate factor* may need adjusting (up or down) once the shunt fraction change has had time to take effect. Set this to 1.7.

3. In State 4, our target systolic blood pressure drops by approximately 5 mmHg. Therefore, we will need to lower the *Resistance Factor: Systemic Vasculature* to accomplish this. A setting 1.4 should work well.

4. To reach our target heart rate of 130, change the *heart rate factor*. You may need to increase or decrease the *heart rate factor* depending on how the new baroreceptor setting affects the heart rate. Set this to 1.25.

5. In State 4 there is a slight increase in the pulse pressure. We need to raise the external and internal elastance parameters to increase the pulse pressure.

   Settings of 1.1 (external elastance) and 2.8 (internal elastance) should bring us close to our target pulse pressure. Note that this returns these parameters to their baseline settings.

6. Once the target endpoint is reached, transfer the appropriate parameter changes to State 4, 'Slight Improvement After Lasix' of the Heart Failure scenario.

7. Add an *Onset* to each parameter change to allow for a smooth change in patient vital signs. A value of 1 to 2 minutes will work well.

For '*Continued Improvement*':

Our target vital signs are:
HR: 110 bpm   BP: 140/85 mmHg   RR: 18 breaths/min SpO_2: 97%

Note: For State 5, remember that the scenario calls for supplemental oxygen (4LPM nasal cannula). Therefore, it is important to apply 4LPM of O_2 in State 5.

ECS Customers: Use the *"Fraction of Inspired Oxygen Override"* (Tabs/Respiratory/Lung) to simulate the application of supplemental oxygen via nasal cannula. Use a setting of 42% for 4LPM.

1. To improve the oxygenation, (SpO_2) decrease the *Shunt Fraction*. Since there is little change in SpO2 between States 4 and 5, the shunt fraction needs lowering only slightly. Change this to 0.20.

2. The *respiratory rate factor* may need adjusting (up or down) once the shunt fraction change has had time to take effect.

3. In State 5, our target systolic blood pressure drops by approximately 15 mmHg. Therefore, we will need to lower the *Resistance Factor: Systemic Vasculature* to accomplish this. A setting of 1.1 should work well.

4. Additionally, we may need to drop our baroreceptor controls to reflect a new control point.

   Drop the *Baroreceptor Maximum Pressure* and *Baroreceptor Minimum Pressure* from 148 to 130 and 108 to 90, respectively.

5. To reach our target heart rate of 110, change the *heart rate factor*. You may need to increase or decrease the *heart rate factor* depending on how the new baroreceptor setting affects the heart rate.

6. Once the target endpoint is reached, transfer the appropriate parameter changes to State 5 of the Heart Failure scenario.

7. Add an *Onset* to each parameter change to allow for a smooth change in patient vital signs. A value of 1 to 2 minutes will work well.

8. Set the *Breath Sounds* to Normal as defined for State 5.

Add Transitions where appropriate:

Consider adding an automatic transition between State 4 (‘*Slight Improvement After Lasix’*) and State 5 (‘*Condition Improved’*). For example, the scenario could automatically transition to the last state after 5 minutes. The transition would appear as follows:

If <u>Time in State</u> **>** 5 minute(s) **then go to** *Continued Improvement*

Summary:

General procedure for reaching patient status target points for each scenario state:

1. Adjust the appropriate respiratory parameters

    a. To adjust the SpO2 use the Shunt Fraction

        i. To lower SpO2: ↑ Shunt Fraction
        ii. To raise SpO2: ↓ Shunt Fraction

    b. To adjust the respiratory rate use the Respiratory Rate Factor

        i. To raise the respiratory rate: ↑ Respiratory Rate Factor
        ii. To lower the respiratory rate: ↓ Respiratory Rate Factor

    c. To adjust the tidal volume use the Tidal Volume Factor

        i. To increase the tidal volume: ↑ Tidal Volume Factor
        ii. To decrease the tidal volume: ↓ Tidal Volume Factor

2. Adjust the appropriate cardiovascular parameters

    a. To adjust the blood pressure use the Systemic Vascular Resistance Factor and the Venous Capacity Factor

        i. To raise BP: ↑ Resistance Factor: Systemic Vasculature
        ↓ Venous Capacity Factor

        ii. To lower BP: ↓ Resistance Factor: Systemic Vasculature
        ↑ Venous Capacity Factor

    b. To adjust the pulse pressure use the External and Internal Elastance

i. To increase Pulse Pressure: ↑ Elastance: Extrathoracic Arteries
↑ Elastance: Intrathoracic Arteries

ii. To decrease Pulse Pressure: ↓ Elastance: Extrathoracic Arteries
↓ Elastance: Intrathoracic Arteries