IN THE KNOWLEDGE BASED PLANNING ERA: THE ROLE OF THE DOSIMETRIST AS THE PREDICTIVE MODEL CREATOR/ADMINISTRATOR

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DISCLAIMER:

- *I am now employed by Varian Medical Systems and my job currently includes promoting Varian's Knowledge Based Planning solution: RapidPlan for Varian's Eclipse Treatment Planning System*
- *While Eclipse RapidPlan is **currently** the only commercially available Knowledge Based Planning solution, KBP software is also utilized as a custom in-house tool at multiple institutions*
- *I will focus on KBP concepts not vendor specific product features where possible (however, screenshots will be utilized where required)*
- *The views expressed in this presentation are mine, and mine alone. They do not represent those of Varian Medical Systems*
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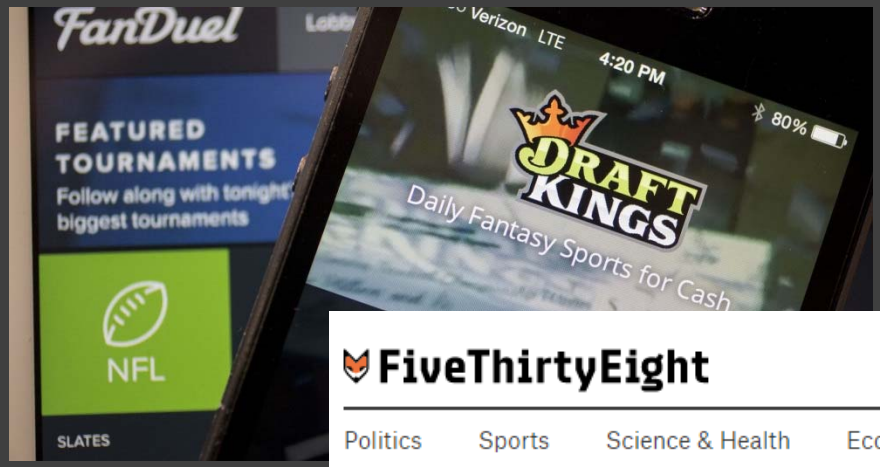
ABOUT ME:

- *I've been a clinical dosimetrist since 2011*
- *I married a dosimetrist and my sister is a dosimetrist*
- *I've been known to be a bit on the extreme side when it comes to things I'm interested in, like plan quality*
- *I have other interests and hobbies including: cars, politics, globalization, technology, home theater and playing board games with my wife, family and friends*
- *But cars are the easiest to make examples with, so there's going to be car analogies throughout this talk…*
- *And, I like questions!*

OUTLINE

- *General overview of Knowledge Based Planning*
  - *What is a "model"*
  - *DVH prediction models vs completed packaged KBP models which include auto-created optimization objectives*
  - *"prebuilt" models vs "homebuilt" KBP models*
  - *Modifying models: changing auto-created optimization objectives / retraining*
  - *Homebuilt model options*
- *Which radiation oncology team member(s) should "own" homebuilt models?*
  - *Physicist alone / physicist and dosimetrist together / dosimetrist alone*
- *Process for creating an institution or MD specific model*
  - *Pick a protocol / treatment site*
  - *Identify past cases, create empty model and import cases into the model*
  - *Train model, analyze cases, identify outliers: first structure then dosimetric*
  - *Consider re-planning outlier cases to utilize them (if they can be "fixed")*
  - *Once satisfied with "model" insert auto-created optimization objectives*
  - *Tune auto-created optimization objectives on validation patients*
- *Discuss future role of the dosimetrist*
  - *Being a model creator/administrator ensures a future the dosimetrist controls*

MACHINE LEARNING MODELS

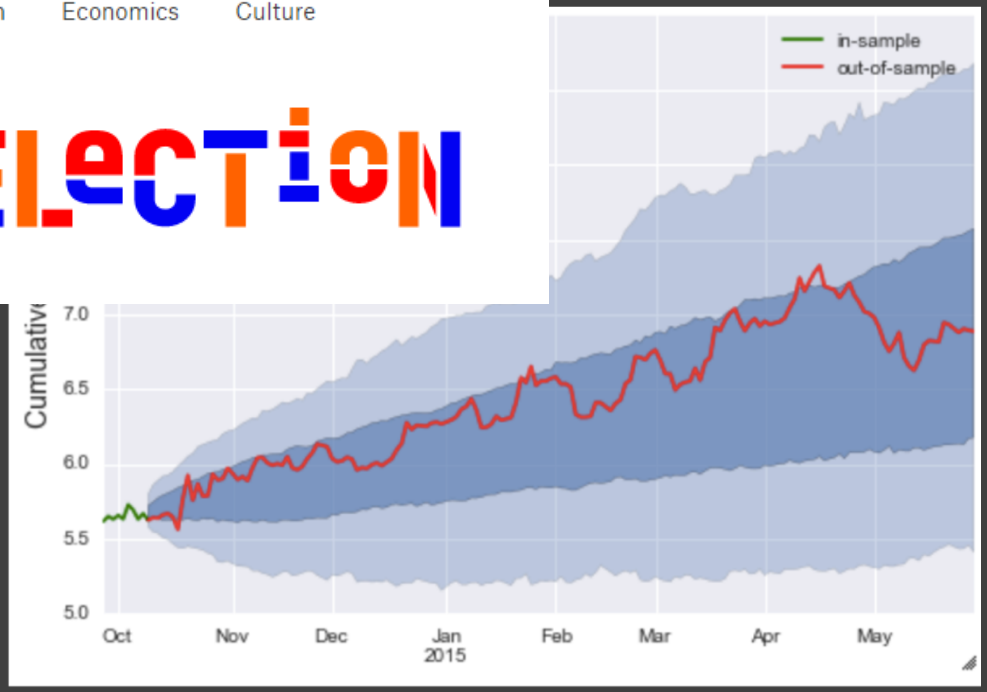


Predictive models are everywhere…

FiveThirtyEight

Politics Sports Science & Health Economics Culture

2016 ELECTION



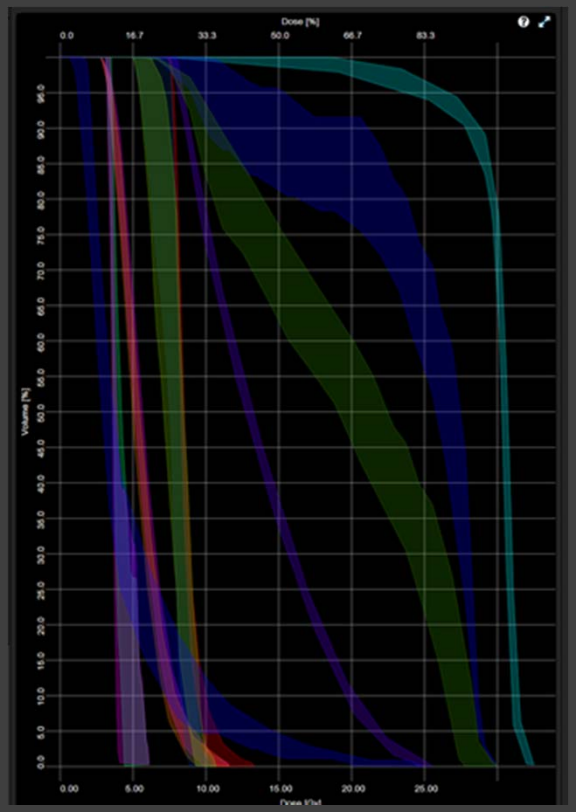
For this talk, when we talk about "models" we will be referring to **DVH prediction models.**

DVH PREDICTION MODEL

- *Uses prior completed treatment plans as a "training set"*
- *KBP software analyzes training set cases for the dose-structure relationship*
  - *analyzing the dose gradient on each structure and it's target proximity/overlap*
  - *"learns" which structures are spared more than others*
- *KBP analyzes all the training set cases simultaneously / cumulatively*
  - *Easier to recognize structure "outliers" (size/target overlap)*
  - *Easier to recognize dosimetric "outliers" (once structure outliers are removed)*
- *With enough consistently planed, high quality cases it can predict DVH for OARs*
  - *At it's core, it is simply a tool that can predict DVH on future cases from past cases*

DVH PREDICTION MODELS VS PACKAGED MODELS

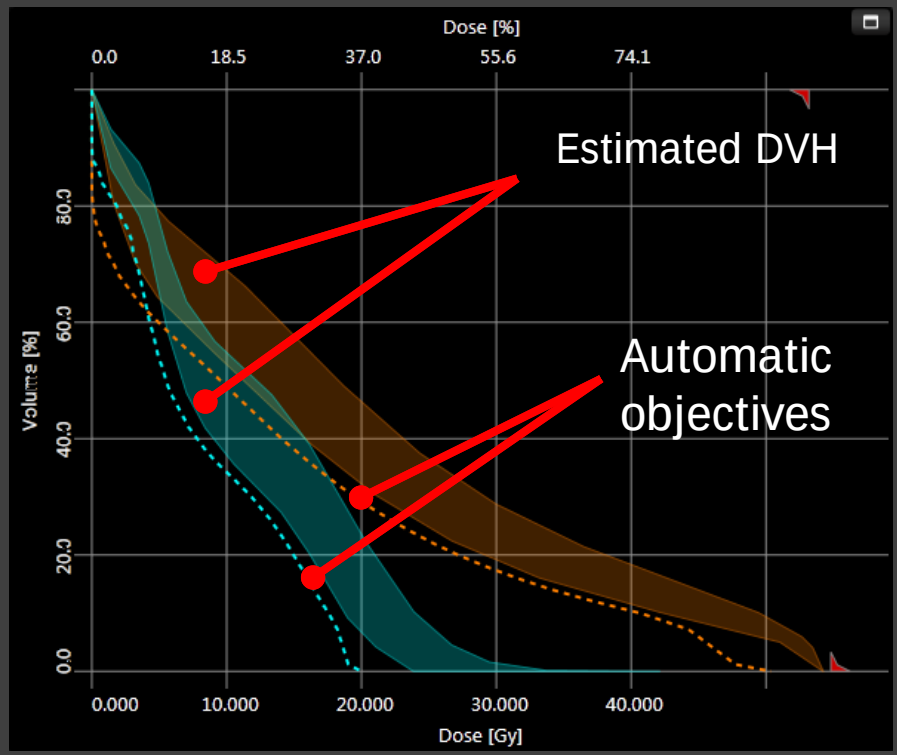
- *However, just creating a model that can generate DVH prediction bands isn't enough*



- *Actually, making a model to create the DVH prediction bands is the "easy" part*

DVH PREDICTION MODELS VS PACKAGED MODELS

- *The "hard" part is using the DVH prediction to generate **good** auto-created optimization objectives for future plans*
- *This step in the model creation and packaging process seems to get the least amount of attention when Knowledge Based Planning is usually discussed*
- *It requires careful tuning of DVH line objectives and/or DVH point objectives and their relative priorities on validation cases*
- *Before a DVH prediction model is completed and packaged as a complete Knowledge Based Planning model **someone** has to create and tune a master set of auto-created optimization objectives which will be applied, relative to the DVH prediction, in the inverse planning optimizer each time the model is used*



PREBUILT VS HOMEBUILT KBP MODELS

- *Knowledge Based Planning systems include prebuilt, complete packaged, KBP models created with a training set of another institution's patients with auto-created optimization objectives tuned my someone else*
- *Depending on your institutional/MD planning goals prebuilt models may or may not work well for your clinic "from the factory"*
- *Also investigating "public knowledge sharing" among peers is also advised by downloading complete packaged KBP models from a model sharing website on the internet which are voluntarily uploaded and shared publicly by Radiation Oncology peers around the world*
- *Private sharing of KBP models via email, USB drive, private files sharing websites is also possible and easy*
- *But, will any of these prebuilt KBP models be a good fit for your treatment plans?*

MODIFYING PREBUILT KBP MODELS

- *Will you as a dosimetrist or your doctor like prebuilt KBP models?*

Many hours of work went into making them look and perform just how they do… for many they are just right, how they come originally.

- *It is very easy to make small changes to any packaged KBP model, you can always adjust the auto-created optimization objectives*

Small changes to the packaging of KBP models can make them more attractive or valuable to their individual user's preferences

FURTHER MODIFYING PREBUILT KBP MODELS

- *If prebuilt, packaged KBP models also include the extracted plan data you can "retrain" the DVH prediction model adding new cases which will change the shape and/or width of the DVH prediction bands*

- *While drastic modification of prebuilt models is possible by retraining, you are still building on the original creator's work*

OPTIONS FOR HOMEBUILT MODELS

- *Use someone else's model to re-plan 20+ of your own past patients, while adding the changes or modifications you or your MD/institution thought were missing from the borrowed model to each case that is re-planned*
  - *Best features of the borrowed model are captured while adding your own "secret sauce"*
  - *All cases are consistently planned*
  - *Those cases become the training set for your own homebuilt model*

- *Use 20+ of your past cases to become the training set for your own homebuilt model*
  - *Will need to eliminate outliers (or re-contour / re-plan them)*
  - *Consider building an initial model and use that model to consistently re-plan the training set cases to train a final model with increased DVH prediction accuracy (recursive method)*

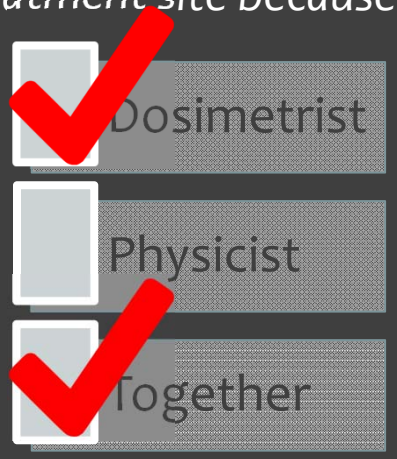
WHICH RADIATION ONCOLOGY TEAM MEMBER?

- *Who should create and "own" homebuilt Knowledge Based Planning models?*
  - *Dosimetrist alone*
  - *Physicist alone*
  - *Together*

- *Let's go through the model creation process, step by step, and answer this question for each step…*

PICK A PROTOCOL / TREATMENT SITE

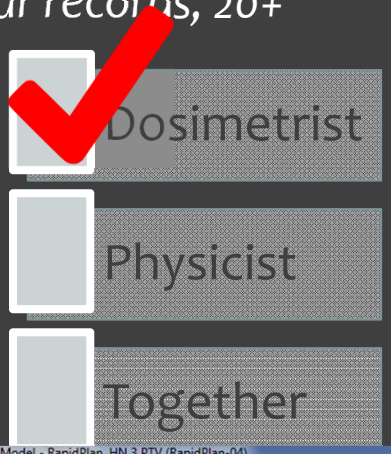
- *DVH prediction models are created specific to an anatomical treatment site because OAR trade-offs are different depending on the tumor location*
- *A clinic-wide discussion on which site would be best for a institution or MD specific KBP model*
- *Or a dosimetrist can decide on their own, in their less busy time, to create a model for a challenging site that is usually time-intensive to plan*

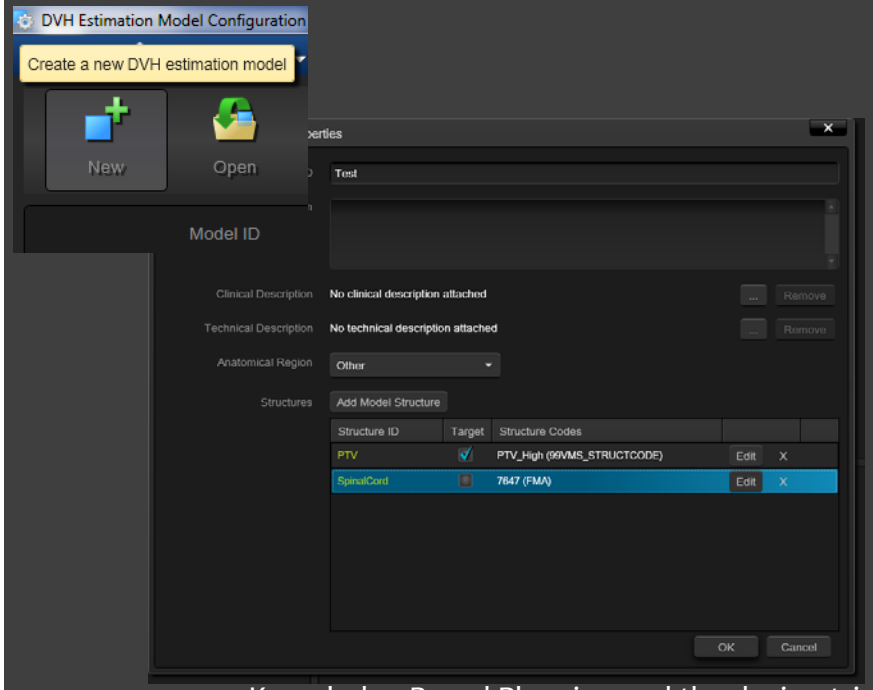


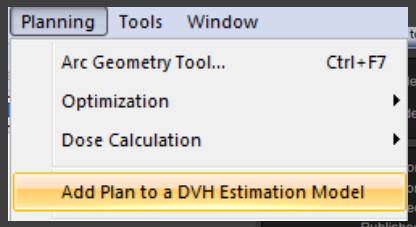
- *Things to consider:*
  - *Do I have at least 20 cases I can use to create the initial model?*
    - *No: Does a model already exist for this treatment site I can modify?*
    - *Yes:*
      - *Will I use an existing model to re-plan my past cases consistently while making the changes I/we want*
      - *Will I be making an original, clean sheet model, from treated or re-planned cases*
  - *Is the target size and/or OAR size (volume) extremely variable?*
    - *If so, plan to use well over 20 cases, at least eventually*

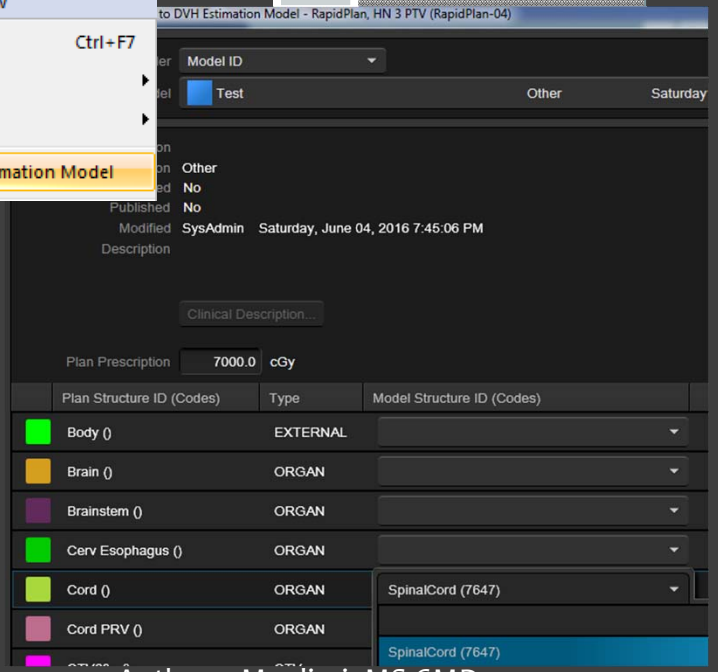
CREATE AND FILL THE MODEL CONTAINER

- *Identify, either through searching your database or checking your records, 20+ patients to use for your model*
- *Create a new model container*
  - *Give the model a working name*
  - *Specify target(s) and OAR structures the model will use*
- *Open each patient, add them to the model / match structures*



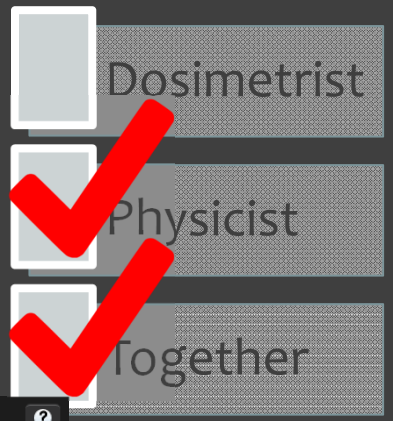


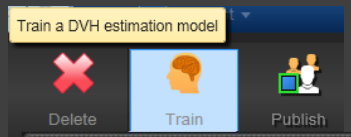




TRAIN ANALYZE AND FIND MODEL OUTLIERS

- *Once all the cases have been added to the model container with matched structures*
  - *Train the model and view summaries*
  - *Analyze structures for outliers*
    - *Geometric plot*
    - *Regression plot*
    - *Exclude outliers, retrain*
  - *Analyze plans for dosimetric outliers*
    - *Residual plot*
    - *Exclude outliers, retrain*



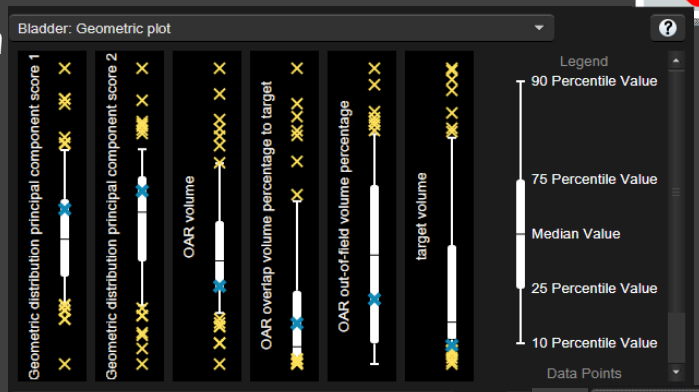


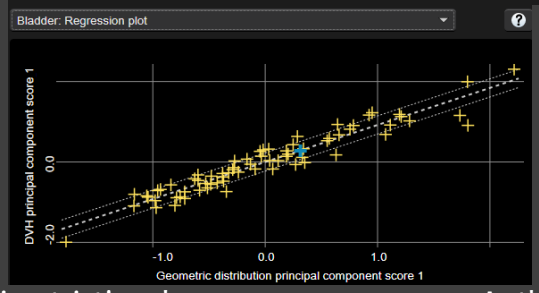
Model: Summary of training results

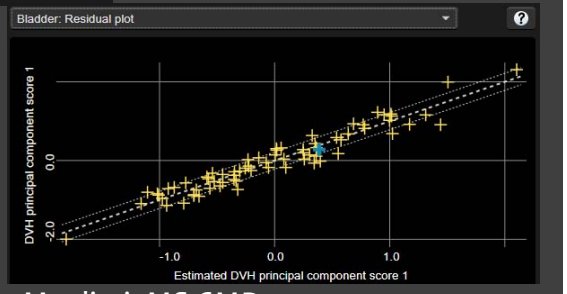
Structure	Trained	R^2	χ^2	Matched	In-field	Outliers
Bladder	Yes	0.910	1.034	71	71	20
FemoralHea	Yes	0.914	1.046	140	140	34
PTV						
Rectum						42

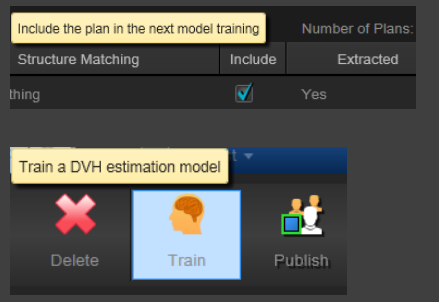
Model: Summary of outlier statistics

Plan #	Bladder	FemoralHeads	Rectum
30	0.542	2.488	4.075
36	3.830	0.818	0.763
52	2.904	1.888	3.682
31	1.281	1.644	3.611
68	3.177	1.923	2.439
47	1.807	1.435	3.098



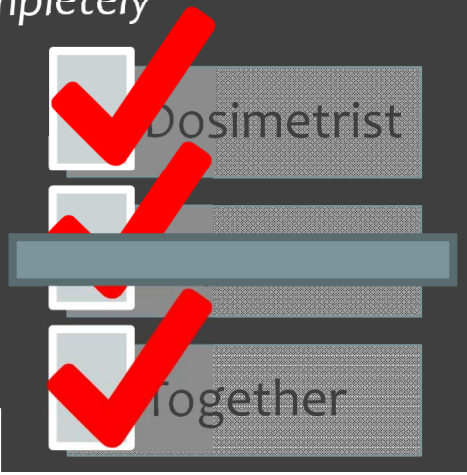


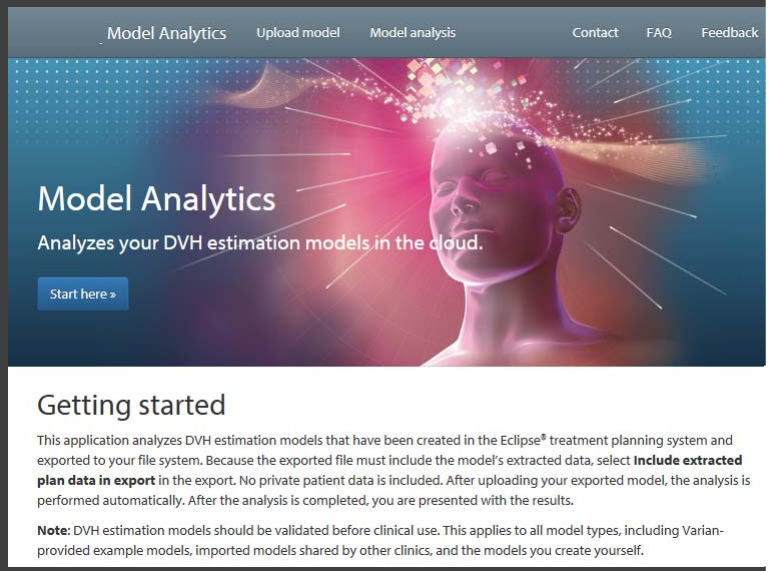


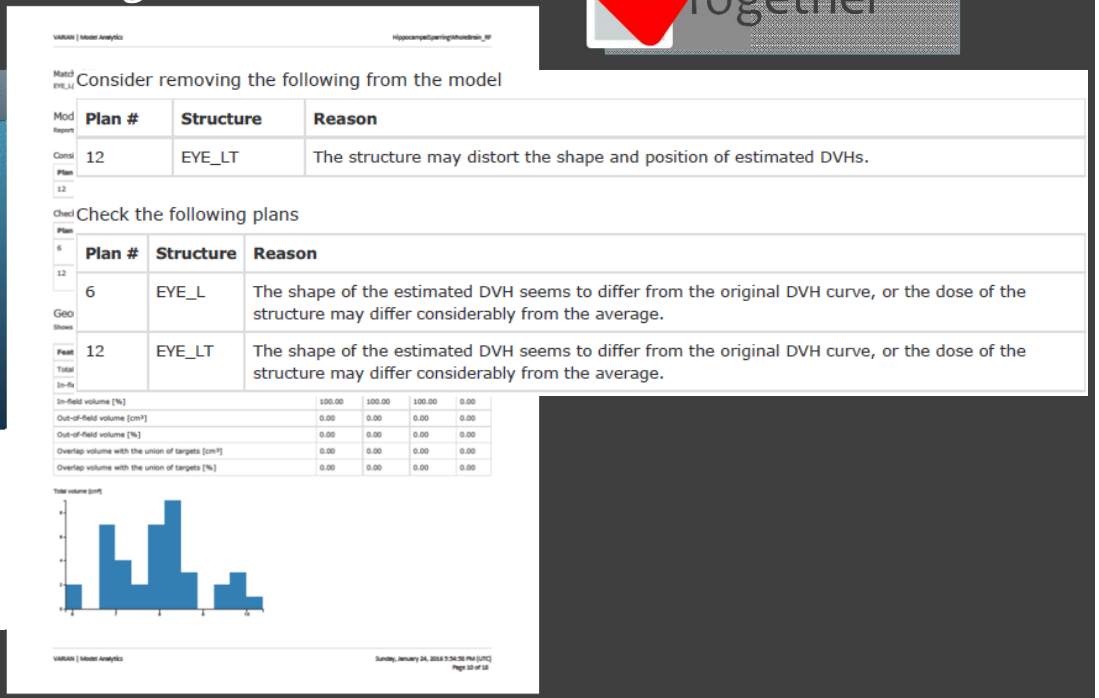


TRAIN ANALYZE AND FIND MODEL OUTLIERS

- *Since that method of finding and eliminating outliers isn't completely straightforward and can be somewhat intimidating…*
- *There is an alternative/companion method of finding and eliminating outliers*
  - *Separate / cloud based software*
  - *Analyzes your model and gives clear suggestions on ways to improve the model including which structures or dose to eliminate or fix*







Consider removing the following from the model

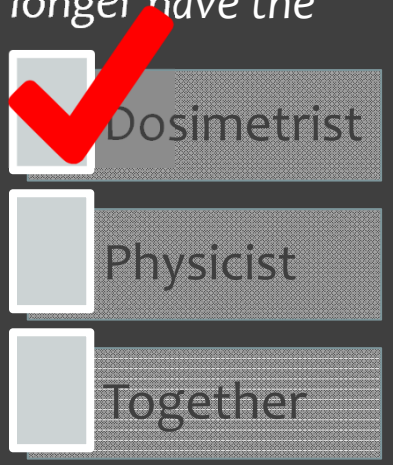
Plan #	Structure	Reason
12	EYE_LT	The structure may distort the shape and position of estimated DVHs.

Check the following plans

Plan #	Structure	Reason
6	EYE_L	The shape of the estimated DVH seems to differ from the original DVH curve, or the dose of the structure may differ considerably from the average.
12	EYE_LT	The shape of the estimated DVH seems to differ from the original DVH curve, or the dose of the structure may differ considerably from the average.

RECONTOUR AND/OR REPLAN OUTLIER CASES

- *If, after excluding outlying plans or individual structures, you no longer have the minimum cases required to predict a DVH for those structures*
- *Or, you simply want to include all possible cases in your model*
  - *Investigate OAR outliers*
    - *Simply mismatched? (lens vs eyes)*
    - *Incorrectly contoured (correct and re-plan)*
    - *Legitimate anatomical outliers (consider adding later)*
  - *Investigate dosimetric outliers*
    - *OAR was unnecessarily undersparred (re-plan)*



Lindsey (Appenzoller) Olsen has stated when creating multiple KBP models for Washington University, **on average, 30%** of the cases originally included in the model training sets had to be re-planned or eliminated from the models.

INSERT AUTO-CREATED OPTIMIZATION OBJECTIVES

- *Once outliers have been eliminated from the DVH prediction model, it's time to begin packaging it*
- *Complete packaged KBP model includes auto-created optimization objectives*
  - *Insert min and max dose(s) for your targets*
  - *Insert line objectives to be generated relative (to the left) of the predicted DVH of all OARs*
    - *Use best judgement for the priorities of the line objectives*
  - *Consider adding DVH point objectives along the line objectives for additional priority at key dose levels*

Target	ID		Vol [%]	Dose	Priority
Yes	PTV_Low	(PTV_Low)			
	Upper		0.0	105.0 %	120
	Lower		100.0	103.0 %	125
	Brain	(50801)			
	Upper		0.0	6000.0 cGy	80
	Line		Generated	Generated	30
	BrainStem	(79876)			
	Upper		0.0	5000.0 cGy	130
	Upper (fixed vol., generated dose)		1.0	Generated	35
	Line		Generated	Generated	30
	Chiasm	(62045)			
	Upper		0.0	5000.0 cGy	130

TUNE AUTO-CREATED OPTIMIZATION OBJECTIVES

- *After reasonable auto-created optimization objectives have been packaged with the model, its time to test and tune!*
  - *use your new KBP model package to plan multiple separate verification patients*
    - *Evaluate results*
  - *Try changing the KBP packaged auto-created optimization objective priorities on the line, point, conformality (NTO), objectives or adding or removing DVH point objectives*
  - *Re-plan verification set again with the new KBP packaged auto-created optimization objective set*
    - *Evaluate results*
  - *Repeat until you find the best compromise of objectives, one master set, that work well for all verification cases*
  - *If one single set of good objectives cannot be found consider taking the best model-created plan on each patient from each phase of testing and using those plans as the training set for a new "final" model. (recursive method)*

MODEL BUILDING TIPS

- *Extensively tune line priorities and DHV point priorities on your auto-created optimization objectives*
  - *Not just on the separate validation cases but also consider the training set cases*
    - *make sure, on average, the complete packaged KBP model can produce cases that are as good or even better than the training set cases*
    - *the model planed cases should always have less variability in plan quality than the training set cases*
- *Create auto-created optimization objectives that can scale relative to Rx*
  - *Use relative rather than absolute dose values so the objectives can scale relative to the Rx*
  - *For OARs with a max dose allowed (spinalcord, etc.) consider creating two sets of max dose constraints, both relative to Rx and absolute dose to also protect the OAR if the Rx is increased beyond what the model was originally tuned for*

MORE MODEL BUILDING TIPS

- *Try to create a non subjective way to judge or grade plan quality throughout model creation process*
  - *Built-in TPS scorecard / plan objectives / clinical protocols*
  - *Homemade software or spreadsheet*
  - *Consider a purpose-built 3rd party plan quality metric analysis tool*

Fields | Dose Prescription | Field Alignments | Plan Objectives | Optimization Objectives

Primary	Prescription				Fraction Dose [cGy]	Total Dose [cGy]	Actual To... Dose [cGy]
☑	GTV_1400	At least	95.0	% receives more than	1330.0	1330.0	1330.0
☐	GTV_1400	At most	66.0	% receives more than	1680.0	1680.0	1376.1
☐	GTV_1400	At most	10.0	% receives more than	1760.0	1760.0	1442.2
☐	Lens_L	Maximum dose		is			5.9
☐	Lens_R	Maximum dose		is			7.9
☐	Eye_L	Maximum dose		is			11.0
☐	Eye_R	Maximum dose		is			12.4
☐	Optic Ne...	At most	0.0	% receives more than	1000.0	1000.0	22.9
☐	Brain St...	At most	0.0	% receives more than	1000.0	1000.0	65.2

arm-anus-ror-2013-plan-challenge

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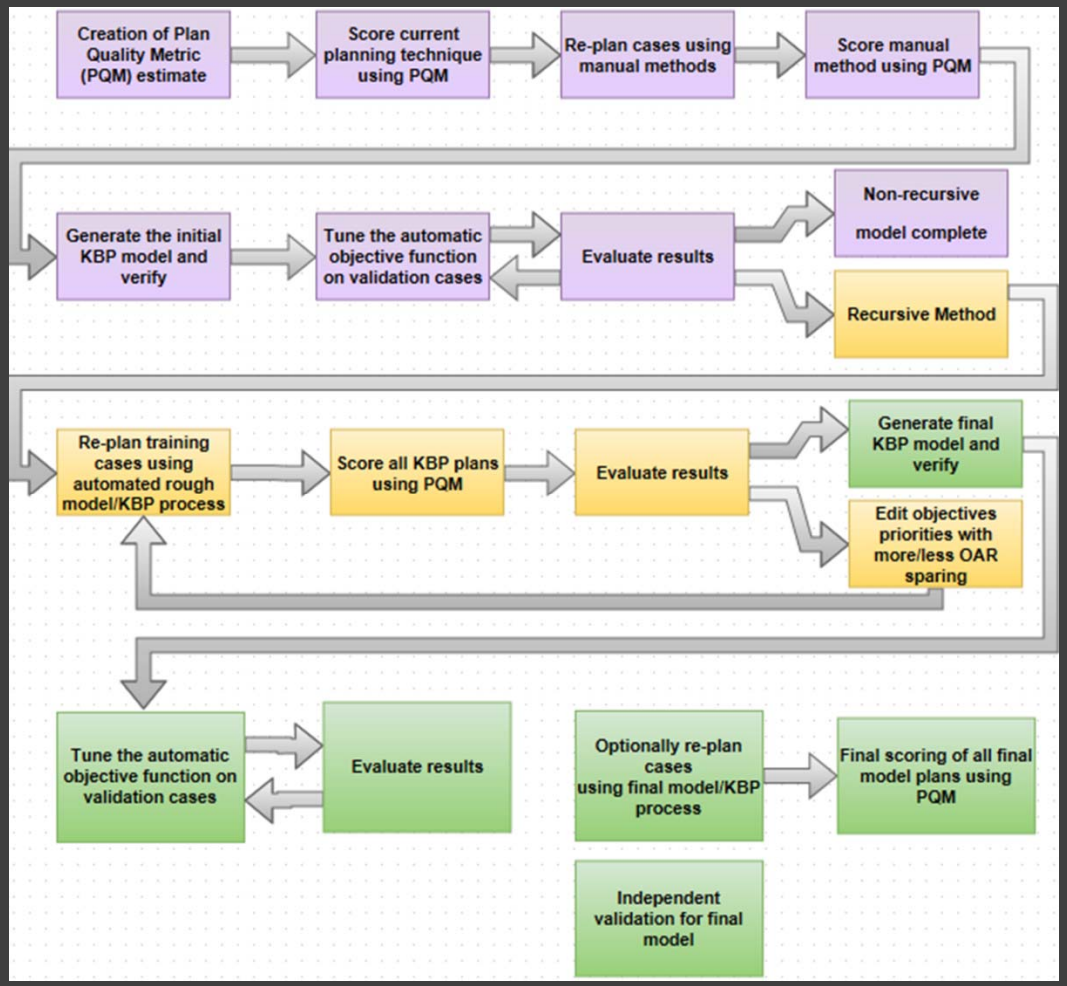
ror plan quality -- 2013 Anus

	A	B	C
1	ror plan quality -- 2013 Anus		max SCORE
2	PTV5040 volume at 50.4Gy	90-95%	20.00
3	PTV5040 volume at 47.88Gy	97-99%	10.00
4	PTV5292 max dose .03cc	52.92-55.44Gy	5.00
5	PTV5040, 95% conform	.45-.8	12.50
6	PTV5040 homogeneity	.1-.04	2.50
7	PTV4500eval AT 45Gy	90-95%	15.00
8	PTV4500eval AT 42.75Gy	97-99%	10.00
9	PTV4500, 95% conform	.35-.6	10.00
10	PTV4500, 20Gy conform	14-11	7.50
11	PTV4500eval homogeneity	.13-.06	2.50
12	Global max location	PTV(5)-CTV(3)	5.00
13	bowel V45 cc	20-3	10.00
14	bowel max	<50Gy	7.50
15	Bladder V35 %	30-5	5.00
16	Bladder V40 %	15-2	7.50
17	genitalia V40 %	5-0%	10.00
18	rectum V30 %	60-35%	7.50
19	femur_r V44 %	5-0%	1.25
20	femur_r V44 %	5-0%	1.25
21			150

Plan Quality Metric Component	Objective(s)	Result	Raw Score	Max Score	Performance
[PTV_WB] V[30.0Gy] (%)	> 90 [≥ 95]	95.2390	10.00	10.00	100.0%
[PTV_WB] D[98.0%] (Gy)	> 22.5 [≥ 25]	26.2081	13.00	13.00	100.0%
[PTV_WB] D[2.0%] (Gy)	< 40 [≤ 37.5]	34.1512	13.00	13.00	100.0%
[PTV_WB] Homogeneity Index [30.0Gy]	< 0.9 [≤ 0]	0.3664	1.19	2.00	59.3%
[PTV_WB] Conformation Number [28.5Gy]	> 0.3 [≥ 1]	0.7421	0.63	1.00	63.2%
[HIPPOCAMPUS_TOTL] D[0.03cc] (Gy)	< 17 [≤ 13]	14.5887	3.62	6.00	60.3%
[HIPPOCAMPUS_TOTL] Mean dose (Gy)	< 12 [≤ 8]	9.2307	6.92	10.00	69.2%
[HIPPOCAMPUS_TOTL] D[100.0%] (Gy)	< 10 [≤ 7]	7.6722	10.86	14.00	77.6%
[CHIASM] D[0.03cc] (Gy)	< 37.5 [≤ 30]	30.2684	2.96	3.00	98.5%
[BRAINSTEM] D[0.03cc] (Gy)	< 37.5 [≤ 33]	32.7213	3.00	3.00	100.0%
[CORD] D[0.03cc] (Gy)	< 37.5 [≤ 25]	26.3241	2.88	3.00	96.0%
[LOPTIC] D[0.03cc] (Gy)	< 37.5 [≤ 30]	29.8358	3.00	3.00	100.0%
[ROPTIC] D[0.03cc] (Gy)	< 37.5 [≤ 30]	29.5932	3.00	3.00	100.0%
[LEYE] Mean dose (Gy)	< 15 [≤ 6]	6.7858	2.74	3.00	91.3%
[REYE] Mean dose (Gy)	< 15 [≤ 6]	6.7668	2.74	3.00	91.5%
[LLACRIMAL] Mean dose (Gy)	< 20 [≤ 10]	7.8789	3.00	3.00	100.0%
[RLACRIMAL] Mean dose (Gy)	< 20 [≤ 10]	8.7612	3.00	3.00	100.0%
[LLENS] D[0.03cc] (Gy)	< 10 [≤ 4]	5.2049	1.60	2.00	79.9%
[RLENS] D[0.03cc] (Gy)	< 10 [≤ 4]	5.3274	1.56	2.00	77.9%
[CHIASM] Max dose (Gy)	< 37.5	31.7133	0.00	0.00	100.0%
[LOPTIC] Max dose (Gy)	< 37.5	30.8812	0.00	0.00	100.0%
[ROPTIC] Max dose (Gy)	< 37.5	30.1599	0.00	0.00	100.0%
[BRAINSTEM] Max dose (Gy)	< 37.5	33.6228	0.00	0.00	100.0%
[CORD] Max dose (Gy)	< 37.5	27.5489	0.00	0.00	100.0%
Total [24 Metrics]			88.69	100.00	88.7%

MORE MODEL BUILDING TIPS

- *If creating a clean sheet model, with no prior model aiding the model creation process, consider building the model in a two phase,* ***recursive method***



FUTURE MODEL MAINTENANCE STRATEGY

- *Model maintenance / administration method for continual improvement*
  - *After your new model has planned a certain number of clinical cases*
    - *Either a fixed number or as a percentage of the of number cases in training set*
    - *Or at a regular intervals (biannually or annually)*
  - *Add model planned cases into the training set of a copy of your current clinical model*
    - *Retrain model*
    - *Verify model on separate validation patient(s) and retune autocreated optimization objectives as necessary*
  - *Publish new model for clinical use and retire previous generation clinical model*
  - *Consider checking that the new model can better plan cases the previous generation model may have struggled with that are now cases included in the current generation's model's training set*
  - *As an ever growing percentage of the cases in the model's training set will be model created cases, consider systematically, slowly removing some original cases during each generation to eventually build a fully recursive model*

THE DOSIMETRIST'S FUTURE ROLE

- *At a crossroads for the role of the Knowledge Based Planning model creator / administrator*

Dosimetrists or **Physicists**?

THE DOSIMETRIST'S FUTURE ROLE

- *Three types of dosimetrists with respect to Knowledge Based Planning?*
  - *Doubters / dismissers*
    - *Want nothing to do with KBP and have a block towards it in their minds*
      - *Either believe it can't be as good*
      - *Or just resistant to any change*
  - *Future users only*
    - *Welcome any tool to make their job easier or faster*
    - *Not interested in diving into the details*
    - *Simply too busy?*
  - *Those who "get it" and would like to become model creators or administrators*
    - *Welcome to the club!*

THE DOSIMETRIST'S FUTURE ROLE

- *Doubters / dismissers*
  - *This used to be me, I thought it was a tool for mediocre to average dosimetrists who needed "help"*
  - *I didn't understand that Knowledge Based Planning is a tool:*
    - *that could not only be used to captures other people's knowledge and apply it towards my future cases…*
    - *that I can use it to capture MY knowledge and apply it towards my future cases*
    - *that can make every future plan I make can use my best plans as a benchmark*
  - *Models I create or administer can be ever improving*
    - *I can spend my time tweaking cases to fine tune the last 5% for the patient rather than trying to get the plan to 90%-95% of what's possible in 24-48 hrs*
    - *I can periodically revisit my model and retrain it with my newest "even better" cases or use it to completely replan the training set and start fresh*

THE DOSIMETRIST'S FUTURE ROLE

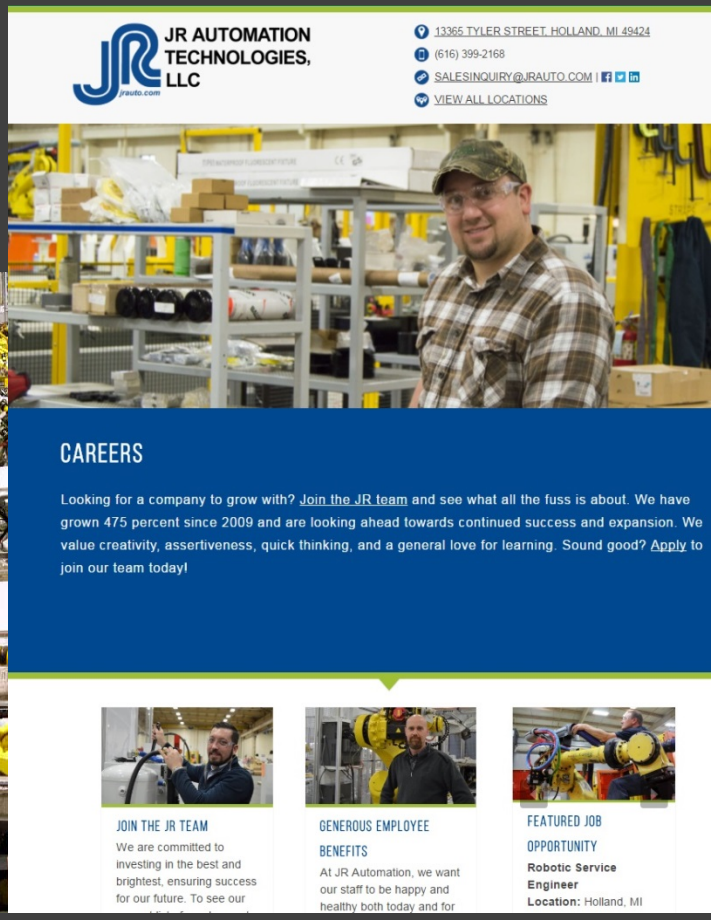
- *Future user only KBP users*
  - *Are you:*
    - *Perhaps just too busy in the clinic?*
    - *Don't consider yourself new technology savvy?*
    - *Thinking most of this presentation was silly or a waste of your time?*
  - *Consider this:*
    - *KBP will save you time*
    - *Perhaps model creation seems like too much for you*
      - *Try to get involved, at least somewhat, in the process*
      - *Definitely at least work on tuning the auto-created optimization objectives before a model is published for clinical use*
      - *Because if the objectives aren't well tuned, you are going to be the one that has to fix them every time*
  - *If model creations isn't for you, at least attempt to work on creating a process for model maintenance / administration with the creator so you can be actively involved in the plans the model helps create in the future*

THE DOSIMETRIST'S FUTURE ROLE

- *Dosimetrists who want to become model creators / administrators*
  - *You obviously need KBP software*
    - *What if your it's not (yet) in the budget or it's not (yet) supported in your TPS?*
      - *Network with your peers in-person and online*
      - *See if there is interest in collaborating on a new KBP model*
      - *Any TPS can make plans for the model training set*
        - » *As long as the final machine planning the case with KBP is capable of making the same type of dose gradients as the plans in the training set, they are compatible*
        - » *Yes, I've heard of successful models made with a training set of helical treatment plans to be delivered on traditional C-arm linacs*
          - *It's really all in how your tune the auto-created optimization objectives*
      - *When the model you help collaborate on is complete, it can be shared with you / your institution and you can apply all that work on future cases, when you do have KBP software*

THE DOSIMETRIST'S FUTURE ROLE

- *Efficiencies are coming, but not all are "knowledge based"*
- *Real time online adaptive therapy… perhaps?*
- *New protocols*
  - *New / updated models*
- *Advances in radiation therapy delivery*
  - *New / updated models*
- *Job security*



QUESTIONS?

- *Special thanks to:*
  - *Vanessa Magliari, CMD*
  - *Rob Foster, MS, CMD, DABR*
  - *My colleagues at Varian & SNC*