

# SYSTEM DYNAMICS AND INSTITUTIONAL DECISION MAKING

*f o r* W A T E R S C E N T E R  
S y s t e m D y n a m i c s



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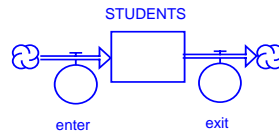
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## OVERVIEW of the SYSTEM:

At the heart of system dynamics are two concepts:

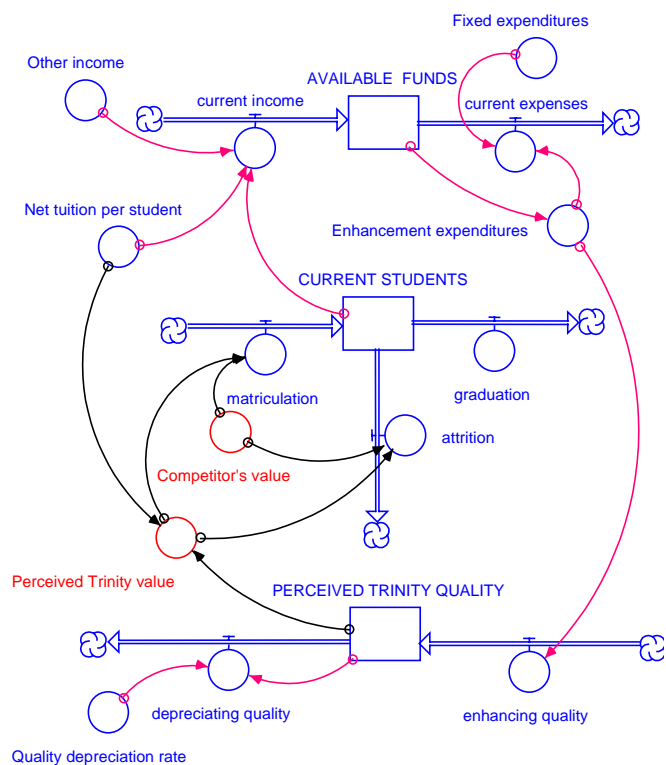
- 1) Systems are dynamic; key elements within them are ever changing as time passes. These elements can be represented by two distinct Building Blocks: **STOCKS** in which “stuff” accumulates and **FLOWS** through which “stuff” moves from Stock to Stock. Consider this as illustrated (at the simplest level) with a student population:



The square (or STOCK) is the accumulation of particular interest to us. The number of students within that Stock change as a result of two FLOWS: one inflow and one outflow, students entering and students exiting, respectively.

- 2) These dynamic changes are controlled by the intrinsic structure of the system itself through the action of one or more feedback loops. Students do not ‘simply’ come and go. They come to a particular institution because something makes that school more attractive than others; they choose to stay or go depending on other factors. These dynamics are not snapshots illustrating simply linear relationships (e.g. “Students come to Trinity College because we have the finest college science labs in Vermont”), but are more realistically described by a complex and continuously evolving interplay between those students, who bring to the institution dollars, which continue to be used to enhance that quality, which keeps science majors in the pipeline, who keep the dollars ... and so on.

A conceptual map of such a mental model is presented to the right. Obviously, this is a gross simplification: at Trinity College, for instance, we know that the “CURRENT STUDENTS” strand is much more complex than depicted. Students of varying types (traditional, non-traditional, graduate) enter at varying stages of their academic careers; so, too, we know that students exit at varying points in their careers through graduation or attrition. We know further that these comings and goings are controlled by a complex array of influences that we wish to explore in this exercise.

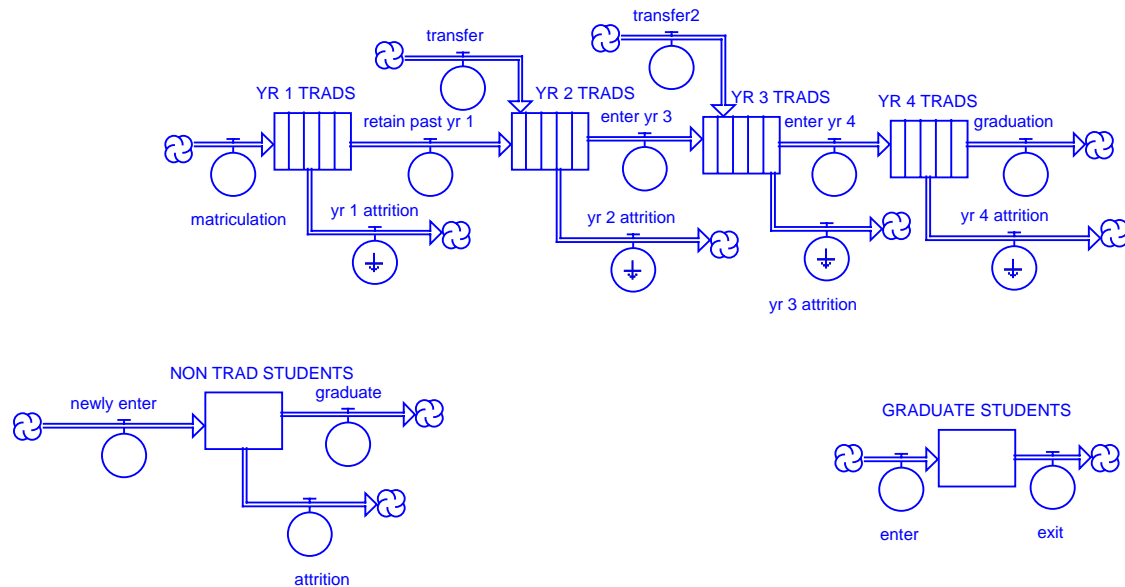


The preceding graphical model represents the mental model we used to begin our explorations. Three fundamental systems interact in this model:

- 1) A system of **CURRENT STUDENTS** that is central in this model. Students enter through matriculation; they leave by means of attrition or by graduation.
- 2) A finance system of **AVAILABLE FUNDS** which receives dollars through a) tuition income and b) other sources and which disburses dollars to pay for a) “fixed” expenditures and b) discretionary expenditures that enhance the quality of the institution.
- 3) A **PERCEIVED QUALITY** sector that is harder to quantify, but which, combined with costs, forms the basis for the cost-benefit analysis with which each student struggles in choosing a college and in deciding to remain at the chosen college. The institution’s quality is not acting in a vacuum, however; students’ choices involve comparing different schools and choosing the one with the best-perceived ‘value.’ This concept of ‘value’ is central to our model.

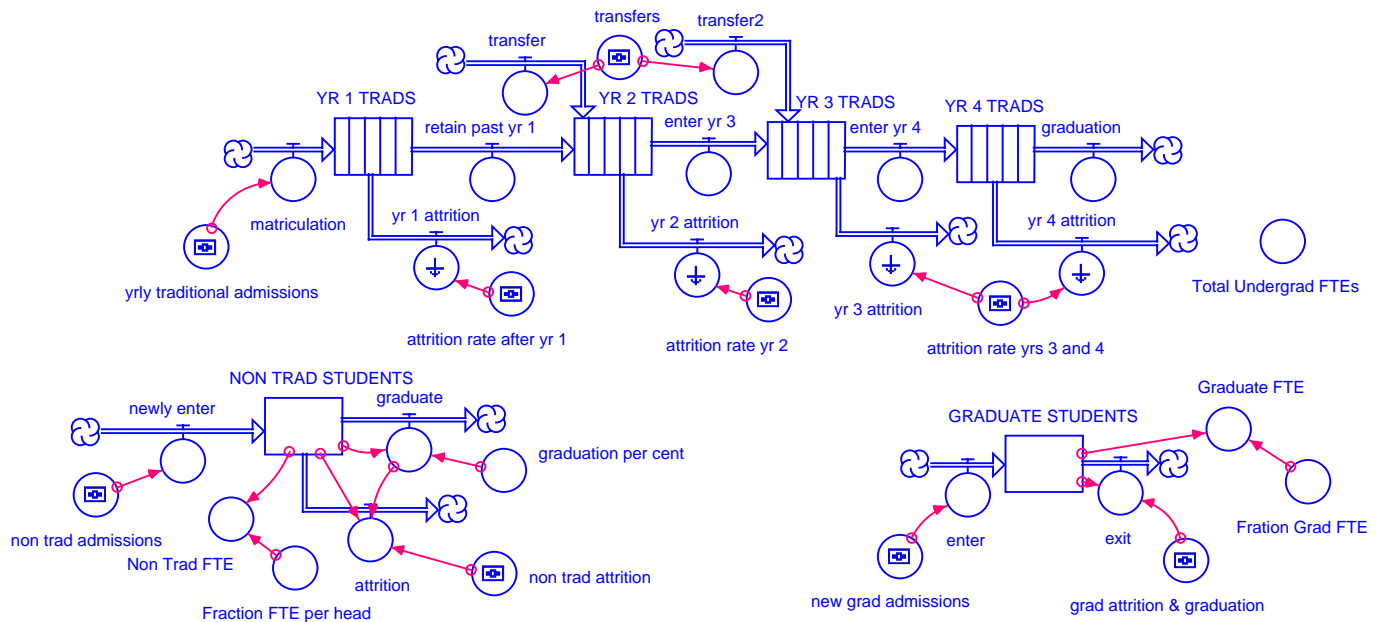
**ELABORATING the STUDENT SECTOR:**

A single Stock of students is much too simplistic to be of much use. A more useful depiction (albeit also more cumbersome) would be:



This elaboration was needed to recognize and depict our belief (our mental model) that each year in the program of a Traditional student will present different opportunities and incentives. Disaggregating the single original student population allows each year (Freshman, sophomore, etc.) to be reflected in greater detail. Also, we needed to recognize the significance of our non-Traditional and Graduate students. Realize, this “Stock/Flow” diagram still lacks critical detail. Such a diagram, as that above, focuses exclusively on the “stuff” of the system (that which is contained in the Stocks and moves through the Flows). What is still missing is the “information” that will ultimately control those Flows.

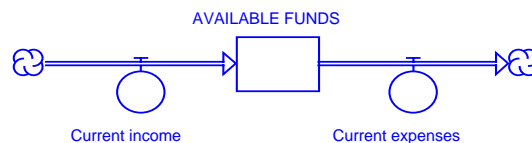
That information requires two additional icons or Building Blocks: the “CONVERTERS” (circles) which contain or process information; and “CONNECTORS” which “deliver” information from one building block to another. The model below contains additional elements to render it more functional. The added Converters are devices that, at this point, allow us to pursue different “what-if” scenarios, imposing new conditions on the model to see how the system responds to certain perturbations. For example, how severe and for how long would you suffer the impact of a recruitment year only 70% as successful as your goal or expectation?



Still, the model of enrollment is incomplete, because it lacks key FEEDBACKS. That is, the numbers of students both matriculating and departing without graduating ARE INFLUENCED by other factors (most critical of which is the combination of cost and perceived quality that we think of as ‘value’). We’ll consider those aspects after we have had the chance to develop the skeletons of those “financial” and “quality” sectors of the model.

### ELABORATING the FINANCE SECTOR:

The simplest way to begin to see finance as a dynamic system is presented below:



which influence the expense side. What you see below is a listing of what we perceive (based on data examined) to be the essentials.

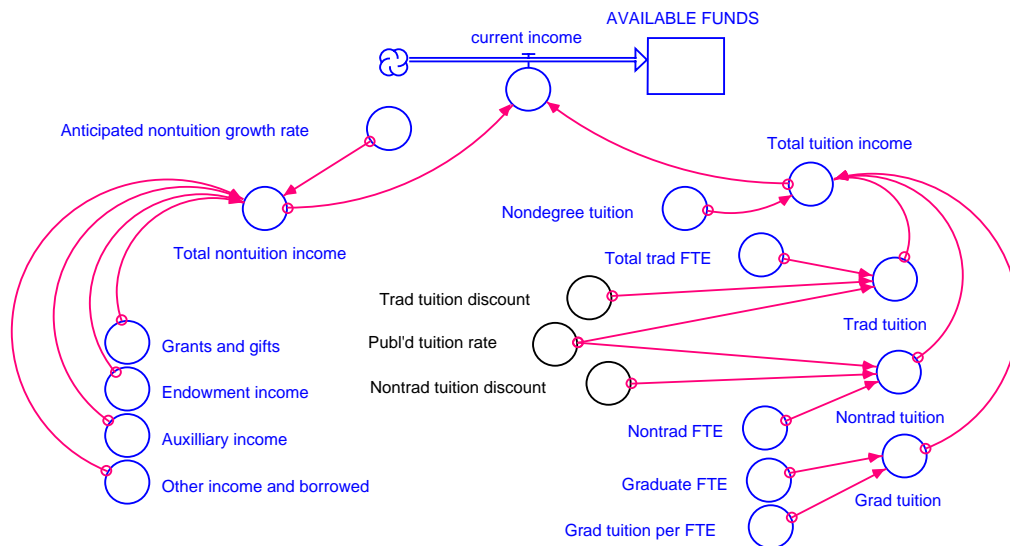
On the **income side**, we have:

**TUITION \$\$**

- 1) "Real" (discounted) undergraduate tuition multiplied by the number of undergrads. At Trinity we need to consider both traditional aged and non-traditional students -- very different dynamics, but both significant.
- 2) Graduate tuition x graduate FTE.
- 3) Tuition from non-degree students.

**OTHER \$\$:**

- 4) Grants and Gifts
- 5) Endowment income
- 6) Auxiliary enterprises
- 7) Other (including borrowed money)

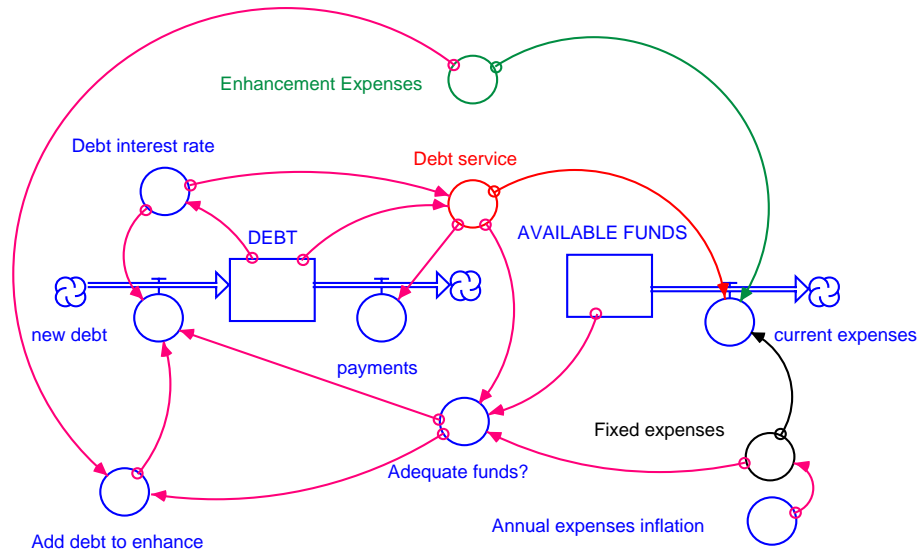


So, too, for prediction purposes, we can factor in increases for growth, as indicated simplistically on the 'non-tuition income' side. Tuition income streams are likely to be changeable as well, but through a complex set of adjustments to enrollment figures, several categories of tuition rates, and institutional discounting policies.

On the **expense side** then:

- 1) All current expenses, for physical plant, for staff, faculty, and administration, and for program (academic and co-curricular) support, are aggregated into a single category (Stock) called "Fixed expenses." They are subject to inflation.
- 2) There is the potential, should there be a surplus in the general funds or after borrowing, to take on "enhancement expenses," that is to add to the existing physical plant, staff, or programs of the college in a way that students will perceive to add quality to their college experience.

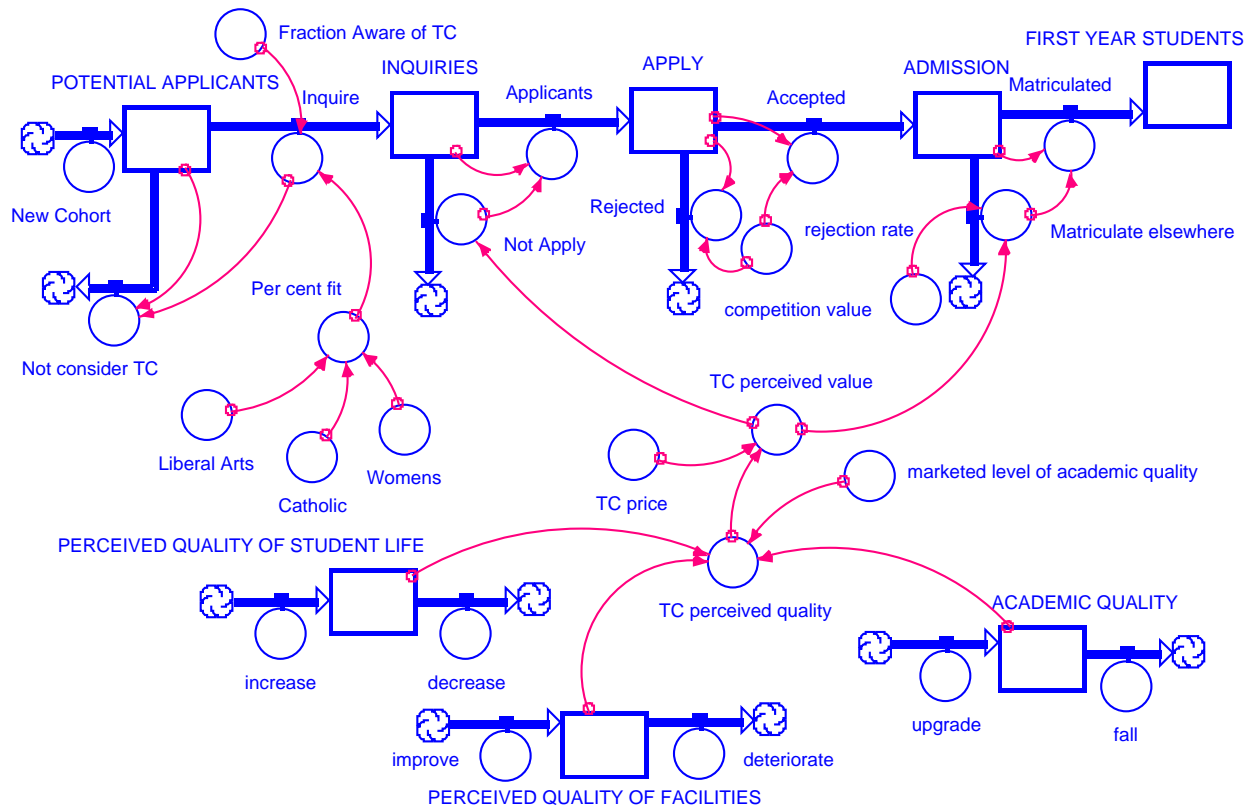
- 3) Finally, there are expenses associated with debt service. Debt can be incurred either to meet underfunded fixed expenses or to provide enhancements to the college.



In this sector of the model, we encounter components that are not so easily manageable in terms of quantitative description. Students can be counted; financial books can be kept. Admittedly, quality can be measured in a variety of ways, but for our purposes (trying to understand and to deal effectively with changing enrollment patterns) a ‘softer’ measure is needed -- students’ *perceptions* of the quality of the College’s program. This modeling of ‘soft’ factors is more difficult, but no less important or valid to a model of this sort. We do, indeed, make judgments and take action based on models of changing institutional quality. Our working models are just more usually our *mental* models that are harder to explain or expose to the scrutiny of others.

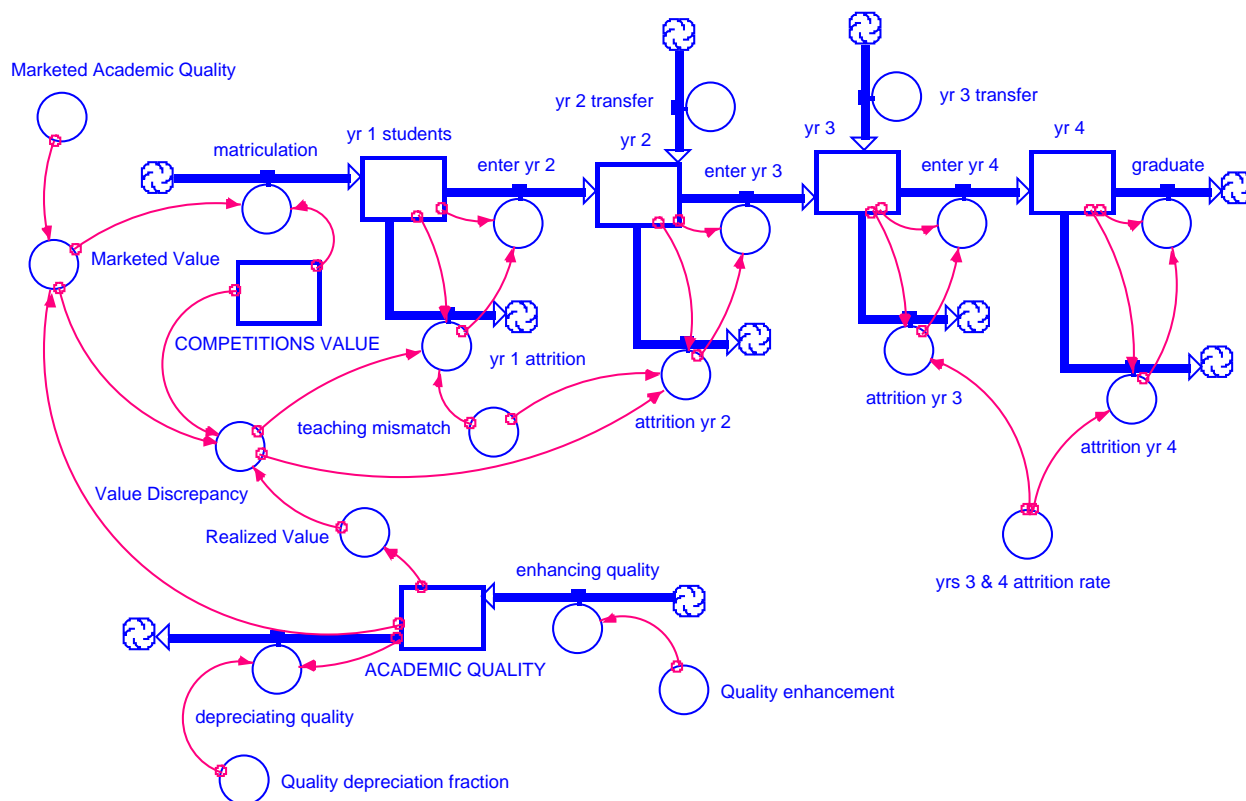
Here, in the development of our mental and simulation models, we quickly realized the “quality” is influential at two major points in time in the system:

- 1) **Recruitment:** Here potential students are trying to gain an accurate picture of the college and determine to what degree it is the *right* institution -- ‘right’ in terms of facilities, flavor of student life, types of programs, and the quality of those programs, including aspects of challenge and support. Their perceptions of ‘quality’ are likely to be colored by two lines of evidence:
  - a) Facts, as reflected by the statistical data available to them, by personal accounts of friends or acquaintances, and campus visits, and
  - b) Marketing, as provided by the College to portray the most positive possible image of the College. Such marketing, ideally, is not false advertising, but it is likely to be very selective advertising.



2) Retention: Here enrolled students are likely to be performing two related analyses:

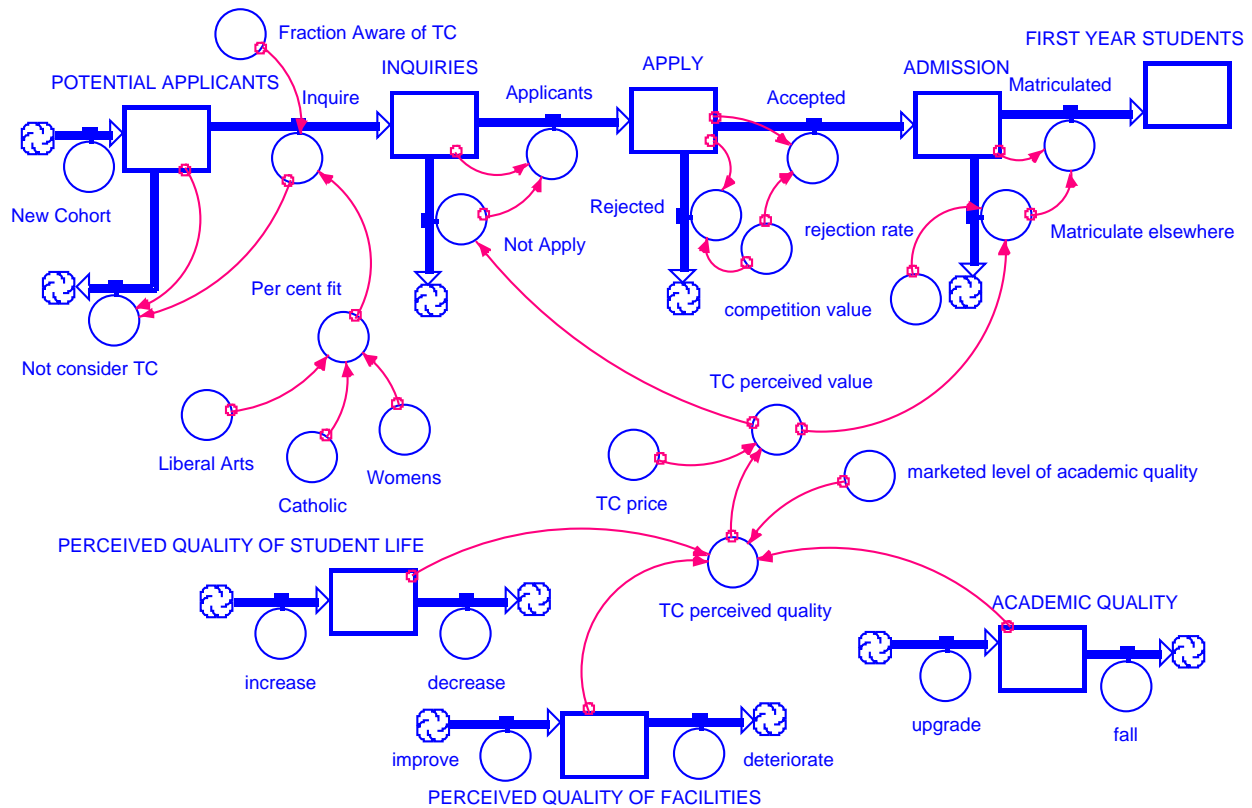
- a) Is the quality of the college experience they encounter as high as they came to anticipate during the recruitment process? Are their programs readily available? Is there sufficient academic rigor and challenge; enough support? Are the student life options and atmosphere attractive? Here an overly aggressive recruiting or marketing program, that raises perceptions of quality to a higher level than justified by the experienced reality, might lead to retention issues.
  
- b) As the students progress through their college careers, is the quality that they encountered on arrival maintained?



## REFINING the ISSUE of QUALITY: INTRODUCING “VALUE”:

As we continued to share and refine our mental models, we quickly realized that “Quality” *per se*, despite the complexity in its definition, is only part of the story (NOTE: the various ‘quality’ elements in the two figures directly above do not directly interact with the Stocks and Flows of the model, but combine with another element. Students do not simply ask the question, “Does this college represent the best quality education available?” but are more likely to ask, “Does this college represent the best available “value,” or quality per dollar spent, in education?” This cost-benefit analysis, linking the financial sector to the quality sector, is central to our thinking).

- 1) **“Value” in a Competitive Market:** “Value” for any product is essentially the quotient of some measure of its quality divided by its price -- ‘bang for the buck.’ Products in the market-place successfully compete by defining an appropriate position within the two scales of quality and cost that defines a “value” that appeals to an adequate number of consumers. Higher education certainly operates in that sort of market. There are schools with a wide diversity of student-life flavors, with widely divergent programs, and with varying amounts of challenge for the intellectually strong and support for students still at lower ability levels. Similarly prices vary widely. Successful schools are those 1) who can define a niche that attracts students, essentially out-competing other schools for that segment of the market (see illustration below) and 2) who can deliver a product that continues to meet the needs of those student it attracts, thereby retaining them.



2) **Defining “Value” for the Individual Student:** Students vary widely in their definition of quality, in their concern about cost, and, therefore, in their perception of value. Size, locale, richness of campus life, religious affiliation, co-ed or single sex, are all qualities that influence the students’ perceptions. Many of those attributes are hard to change, or at least represent long time horizons for meaningful change; they are not likely leverage points for short term changes in institutional image. Academic program is more amenable to shifts. Programs can be added, deleted, or re-structured over periods ranging from several months to a couple years. In addition to such qualitative aspects of the academic program, colleges can make conscious choices as to the intellectual level at which those programs are aimed. Are they aimed at the level of the intellectually accomplished, so that ‘merely’ average students would have trouble succeeding? Conversely, are they focused at the intellectually developing student, so that the already accomplished scholar would be largely unchallenged? Either approach is valid and valuable in today’s higher education environment. Problems arise only when students and institutions are not clear with each other on their personal needs and desires on the one hand, and on their institutional abilities to serve students, especially outside the ‘norm’ of the student body.

The other piece of the “value” equation, costs, ought to be more straightforward. Tuition and fees, plus room and board, plus incidentals equal the cost for the individual student. The first two items will be the same for all students at a given school; the third will vary between students, but they can exercise considerable control on those costs. Schools offering more ‘quality’ in their programs tend to cost more, but, as long as quality and cost both rise together, the schools still represent good value. This value can often be further enhanced by schools with significant non-tuition sources of income that can be utilized to support

enhanced quality but without adding to the students' costs. Within an individual school today, however, wide variations in value may exist, as many schools are differentially discounting the costs for their desirable students through 'merit-based' scholarships. A school with an average quality may be able to compete for more able students by such a price reduction, raising the average school's perceived value to a level more comparable to the higher quality college.

In our model we felt obliged to recognize the potentially changing profile of student intellectual ability, dividing the student population into five, admittedly risky, categories based on quintiles (1/5th intervals) of national SAT scores. A student may fall into the lower fifth or the fourth fifth. A college will matriculate students with a range of academic abilities. The implications of that variation will play out as a result of a number of factors that are incorporated in the model:

- marketed quality of the college for each ability group (does the college claim to offer programs and services to meet the needs of each group?)
- realized quality of the college for each ability group (does the college actually deliver the programs and services needed to meet the needs of each group?)
- cost to the college to provide the programs and services to meet the needs of each group
- actual tuition cost for each ability group (how does the college distribute its tuition discounting across these groups?)
- the academic level at which the college effectively delivers its academic program

The interaction of these factors will define what students will be attracted to the college, which students the college will be able to work with effectively, which students will choose or be able to continue at the college, and whether the college is effectively and efficiently investing its available enhancement funds.

## **DESCRIBING the MODELING PROCESS:**

A system dynamics approach to this sort of institutional management issue is more than a few academic pinheads sitting down and crafting a computer program to solve a particular problem. *The process in which we are engaged is at least as important as the eventual product we obtain.* Apart from the resultant computer model, this process obliges us and supports us

- in very precisely and explicitly exploring our mental models of how this system operates,
- in exposing and communicating those mental models to others,
- in opening ourselves to the mental models and perceptions of others,
- in playing 'what-if' games with a variety of policy options, and
- in recognizing and filling gaps in our factual or perceptual foundations.

As we proceeded through the development of this model, we began with a very generic and relatively simple view of the interactions of enrollment, finance, and something we called 'quality.' As we began to elaborate each sector of the model, we had to express and test our understanding against the views and experiences of others in the student life and finance operations. Each sector quickly became more elaborate, cumbersome, but also more realistic as we pursued this exploration. It quickly became obvious, for instance, that a single "attrition" factor would not be adequate; attrition is very different in magnitude and cause(s) depending if we are talking about first year or senior students, about traditional or non-traditional students, about our 'best and brightest' or our marginal students. Similarly the 'quality' of the college

receives contributions from a number of sources -- physical plant, student life, and academic program, to acknowledge a portion. Different mixes of factors with different weightings define the quality for different ability groups of students. Students in the top ranks will look for and utilize a very different suite of institutional resources than will the struggling student. We were continuously led into asking ever-deeper and ever-better questions as we worked through the layers of logic to construct this simulation.

The model is not completed; it may never be finished, since each step forward reveals additional possible steps. We will continue to refine it and to use it to engage the planners and executors of institutional policy at Trinity College. Already it has proven valuable in providing a common focus and language for administrators from the academic, financial, and student life programs of the College as we move collectively into the future trying to make the best possible decisions for a college uncomfortably dependent on the semester by semester tuition payments of a relatively small student body. We have little margin of error in our planning and operations; any tool that strengthens and brings our mental models into congruence and allows us to test our assumptions is extremely important. This model, and the process that brought it to life, have both done that and promise to continue to pay dividends into the future.

#### **A SIMPLE ILLUSTRATION OF THE MODEL:**

The following is a simple, or simplistic, illustration of how the current model is structured and how it can be used to explore a couple of basic policy options.

Baseline scenario: A relatively simple scenario is presented.

- Matriculating students are spread evenly over all five SAT quintiles,
- College marketing pitches the institution as providing a reasonable education for all possible students,
- In fact, the college quality matches its marketing only for students in the central SAT quintile; we teach most effectively in the middle,
- Income is derived overwhelmingly from tuition and room and board of our current students,
- Expenses and tuition both inflate at reasonable rates; little significant resource is put into enhancing the quality of the college's program, and
- There is viable competition for our potential and current students in the form of other institutions.

Under the conditions defined in this scenario, the College suffers continually falling enrollment and increasing cash flow problems. In short, the College is unable to compete with those other institutions.

10:20 PM Tue, Jan 26, 1999 Table 4: p1 (Income, Expenses & Debt)

Years	total income	total expenses	new debt	DEBT	Budget surplus or de	GENERAL FUNDS
1998	\$8,550,000	\$7,800,000	\$0	\$0	\$750,000	\$8,550,000
1999	\$8,638,979	\$8,112,000	\$0	\$0	\$526,979	\$9,300,000
2000	\$8,660,795	\$8,436,480	\$0	\$0	\$224,315	\$9,826,979
2001	\$8,541,628	\$8,773,939	\$0	\$0	(\$232,311)	\$10,051,294
2002	\$8,499,873	\$9,124,897	\$0	\$0	(\$625,024)	\$9,818,983
2003	\$8,504,811	\$9,489,893	\$0	\$0	(\$985,081)	\$9,193,959
2004	\$8,506,090	\$9,869,488	\$0	\$0	(\$1,363,398)	\$8,208,878
2005	\$8,514,422	\$10,264,268	\$0	\$0	(\$1,749,846)	\$6,845,480
2006	\$8,529,653	\$10,674,839	\$0	\$0	(\$2,145,185)	\$5,095,634
2007	\$8,551,675	\$11,101,832	\$0	\$0	(\$2,550,157)	\$2,950,449
Final				\$0	(\$2,965,490)	\$400,292

10:20 PM Tue, Jan 26, 1999 Table 1: p4 (Traditional Undergraduates)

Years	Total 1st yr traditional st	Total 2nd year traditional	Total 3rd year traditional	Total 4th year traditional	Total traditional students
1998	100	100	100	100	400
1999	100	90	110	100	400
2000	92	88	100	110	390
2001	84	83	96	100	363
2002	77	77	91	96	340
2003	71	71	85	91	317
2004	65	66	79	85	295
2005	59	62	74	79	275
2006	54	58	70	74	256
2007	50	54	66	70	239
Final	46	50	62	66	223

Policy scenario 1: Enhanced marketing presents the College as having 40% higher quality than previously presented. Nothing, in fact, has changed in terms of actual quality. Any increased recruitment is quickly counterbalanced by increased attrition as the College's reality does not measure up to the expectations of the incoming students. After ten years both enrollments and finances are slightly worse than in the baseline scenario.

10:37 PM Tue, Jan 26, 1999 Table 4 : p1 (Income, Expenses & Debt)

Years	total income	total expenses	new debt	DEBT	Budget surplus or de	GENERAL FUNDS
1998	\$8,550,000	\$7,800,000	\$0	\$0	\$750,000	\$8,550,000
1999	\$8,570,728	\$8,112,000	\$0	\$0	\$458,728	\$9,300,000
2000	\$8,512,175	\$8,436,480	\$0	\$0	\$75,695	\$9,758,728
2001	\$8,333,306	\$8,773,989	\$0	\$0	(\$440,684)	\$9,834,424
2002	\$8,309,752	\$9,124,897	\$0	\$0	(\$815,145)	\$9,393,790
2003	\$8,352,229	\$9,489,893	\$0	\$0	(\$1,137,663)	\$8,578,645
2004	\$8,376,233	\$9,869,488	\$0	\$0	(\$1,493,255)	\$7,440,982
2005	\$8,403,909	\$10,264,268	\$0	\$0	(\$1,860,359)	\$5,947,727
2006	\$8,435,546	\$10,674,839	\$0	\$0	(\$2,239,293)	\$4,087,368
2007	\$8,471,413	\$11,101,832	\$0	\$0	(\$2,630,419)	\$1,848,075
Final				\$0	(\$3,054,141)	(\$782,344)

10:37 PM Tue, Jan 26, 1999 Table 1 : p4 (Traditional Undergraduates)

Years	Total 1st yr traditional st	Total 2nd year traditional	Total 3rd year traditional	Total 4th year traditional	Total traditional students
1998	100	100	100	100	400
1999	100	84	110	100	394
2000	92	80	94	110	376
2001	84	77	88	94	344
2002	77	72	85	88	323
2003	71	68	80	85	304
2004	65	63	76	80	285
2005	60	59	71	76	266
2006	55	56	67	71	249
2007	50	52	64	67	233
Final	46	49	60	64	219

Policy scenario 2: Since the truly dangerous aspect of the baseline is incipient bankruptcy after ten years, this scenario simply increases tuition by 7.5% annually instead of the 5% annual increase in the base scenario. After ten years, the finances are, indeed, better than in the baseline, but student enrollment is noticeably less (with increased costs, the College is less able to compete in the ‘value’ arena against other institutions) and the trends in both finance and enrollment are steeply worsening.

10:44 PM Tue, Jan 26, 1999 Table 4: p1 (Income, Expenses & Debt)

Years	total income	total expenses	new debt	DEBT	Budget surplus or def	GENERAL FUNDS
1998	\$8,674,800	\$7,800,000	\$0	\$0	\$874,800	\$8,674,800
1999	\$8,763,931	\$8,112,000	\$0	\$0	\$651,931	\$9,549,600
2000	\$8,787,371	\$8,436,480	\$0	\$0	\$350,891	\$10,201,531
2001	\$8,671,210	\$8,773,939	\$0	\$0	(\$102,729)	\$10,552,422
2002	\$8,635,982	\$9,124,897	\$0	\$0	(\$488,915)	\$10,449,694
2003	\$8,660,006	\$9,489,893	\$0	\$0	(\$829,887)	\$9,960,778
2004	\$8,680,569	\$9,869,488	\$0	\$0	(\$1,188,919)	\$9,130,891
2005	\$8,676,064	\$10,264,268	\$0	\$0	(\$1,588,204)	\$7,941,972
2006	\$8,679,529	\$10,674,839	\$0	\$0	(\$1,995,309)	\$6,253,768
2007	\$8,686,339	\$11,101,832	\$0	\$0	(\$2,415,493)	\$4,358,459
Final				\$0	(\$2,814,048)	\$1,942,966

10:44 PM Tue, Jan 26, 1999 Table 1: p4 (Traditional Undergraduates)

Years	Total 1st yr traditional st	Total 2nd year traditional	Total 3rd year traditional	Total 4th year traditional	Total traditional students
1998	100	100	100	100	400
1999	100	90	110	100	400
2000	89	88	100	110	388
2001	79	81	96	100	357
2002	71	74	89	96	330
2003	63	67	82	89	301
2004	56	61	75	82	274
2005	50	54	69	75	248
2006	45	49	62	69	224
2007	40	44	57	62	202
Final	35	40	52	57	185

Both policy scenarios represent admittedly simplistic solutions to a complex problem. Both solutions, however, are time-honored elements of the response of many institutions to concerns about falling enrollments and/or income streams. The model is capable of working with as complex a policy as you care to impose. For the sake of illustration here, we chose a relatively simple pair of options.